Run II at the Tevatron

View of Particle Physics & Standard Model

Higgs Search: Now & Future

The Tevatron

Status of DØ experiment

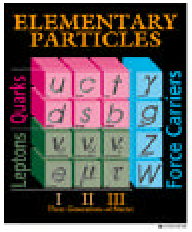
Harry Weerts
Michigan State University
Co-spokesman of DØ experiment

Experimentalist View of Particle Physics

A lot of exp. & theory effort over last 3 decades to establish
and now well tested

Many experiments
continuing to test
and fine tune

Standard Model



Theory only

A **little subtle** aspect is missing/not understood:
Electroweak symmetry breaking (EWSB) and generation of mass
(leptons, quarks and force carriers) not experimentally verified
(Higgs mechanism)

Aspect of this talks

Many parameters in SM not predicted: model and not a theory

There must be more than just SM: GUTs, SUSY, Technicolor, Extra Dimensions

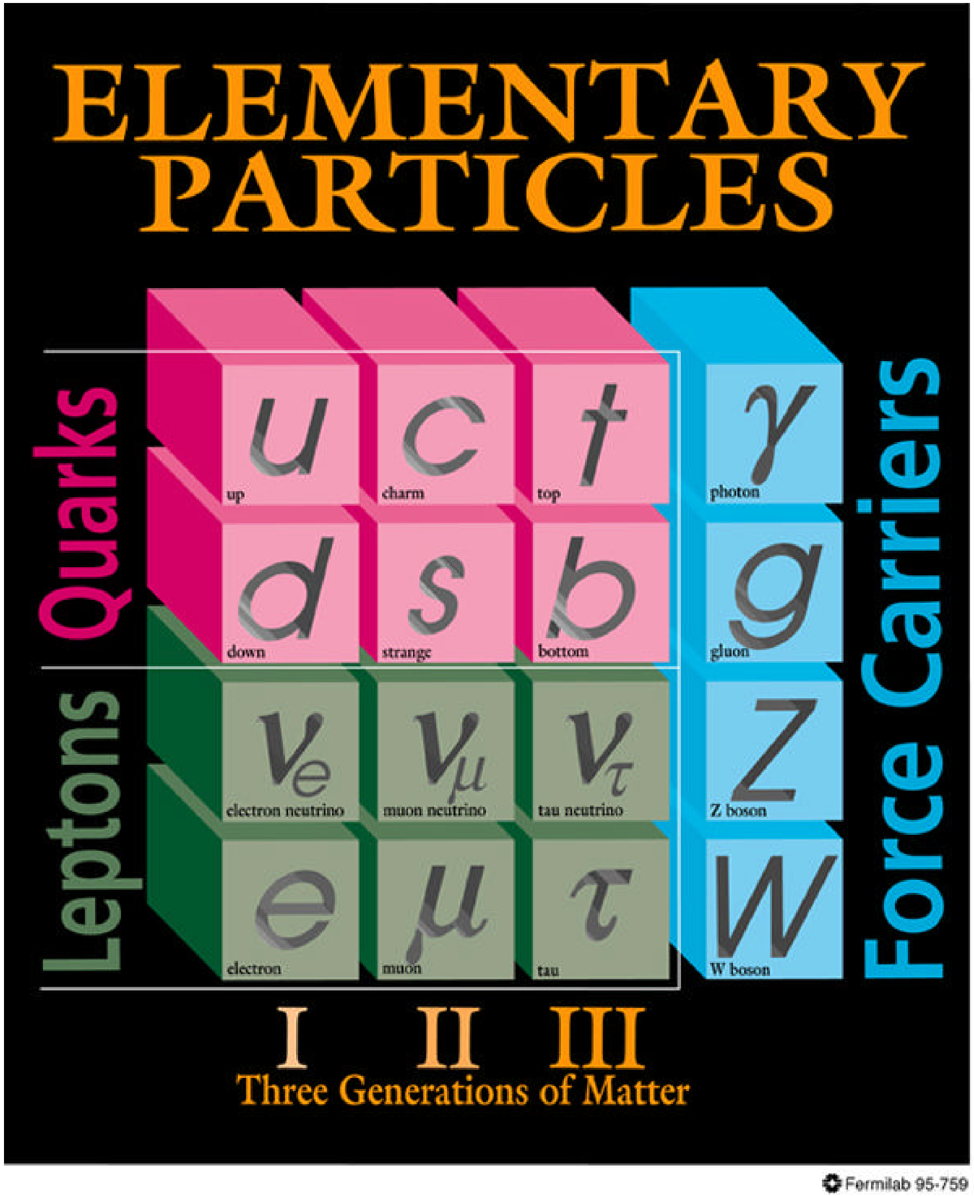
Need experiment to point the way

Many exp. efforts in HEP (not directly going to EWSB): important, but not mentioned here:

Neutrino masses & mixing, extensive B physics programme, astrophysics (missing matter, missing energy, neutrinos, very high energy showers, etc.)

The Standard Model constituents & forces

Quarks and Leptons are building blocks of matter



Bosons (γ,g,W,Z) are mediators of the known forces: E&M, Weak and Strong

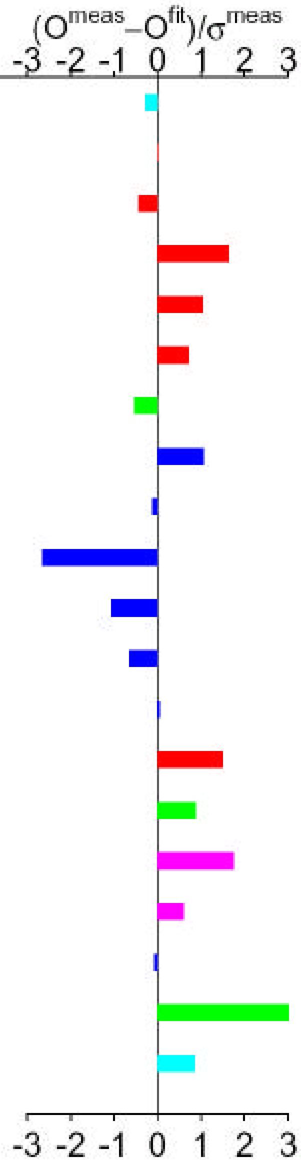
u,*d* and *e* make up all life

Gravity not included

How well does SM work ?

Winter 2002

	Measurement	Pull
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02761 ± 0.00036	-.27
m_Z [GeV]	91.1875 ± 0.0021	.01
Γ_Z [GeV]	2.4952 ± 0.0023	-.42
σ^0_{had} [nb]	41.540 ± 0.037	1.63
R_l	20.767 ± 0.025	1.05
$A^{0,l}_{fb}$	0.01714 ± 0.00095	.70
$A_l(P_\tau)$	0.1465 ± 0.0033	-.53
R_b	0.21646 ± 0.00065	1.06
R_c	0.1719 ± 0.0031	-.11
$A^{0,b}_{fb}$	0.0994 ± 0.0017	-2.64
$A^{0,c}_{fb}$	0.0707 ± 0.0034	-1.05
A_b	0.922 ± 0.020	-.64
A_c	0.670 ± 0.026	.06
A_l(SLD)	0.1513 ± 0.0021	1.50
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	.86
m_W [GeV]	80.451 ± 0.033	1.73
Γ_W [GeV]	2.134 ± 0.069	.59
m_t [GeV]	174.3 ± 5.1	-.08
$\sin^2\theta_W(\nu N)$	0.2277 ± 0.0016	3.00
$Q_W(Cs)$	-72.39 ± 0.59	.84



Pull distributions in units of σ_{meas}

Measurements of many experimental observables, compared to fit to the Standard Model.

Perfect agreement means everything is at "0"

Standard model VERY WELL established; no real deviations

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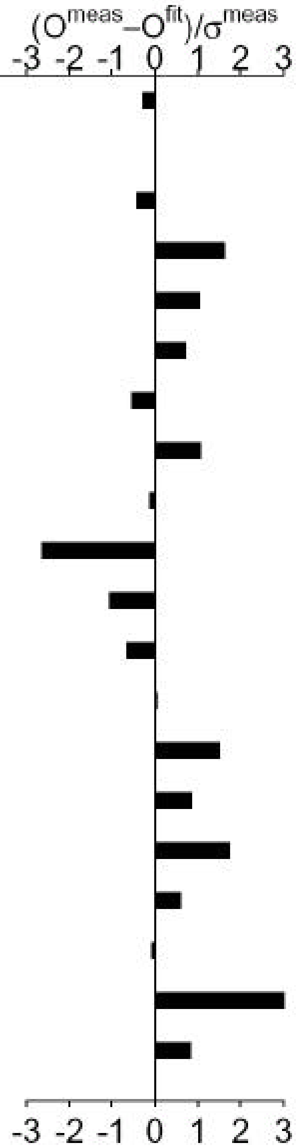

Pull distributions in units of σ_{meas}

Measurements of many experimental observables, compared to fit to the Standard Model.

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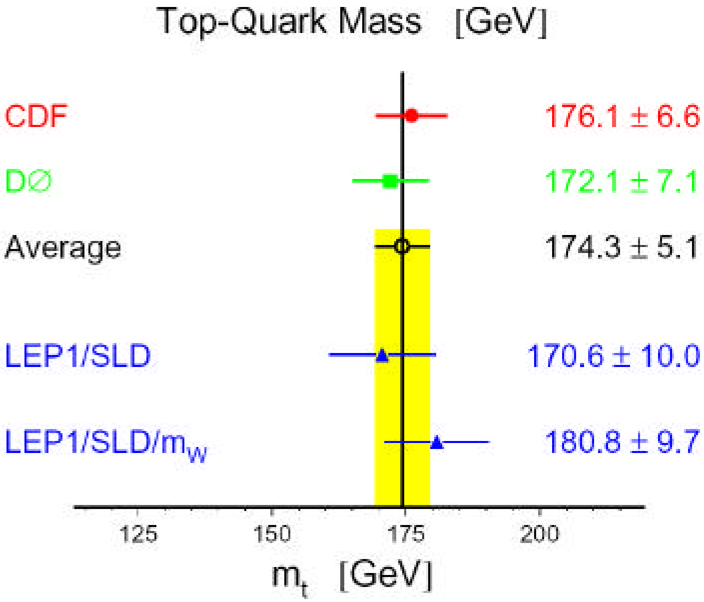
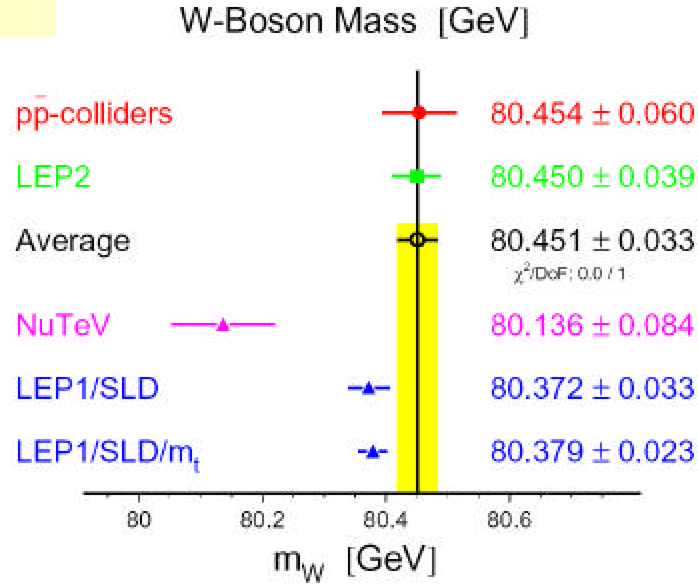
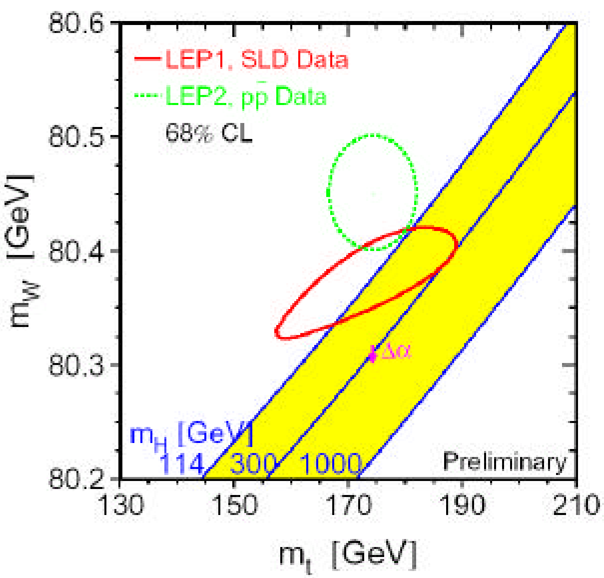
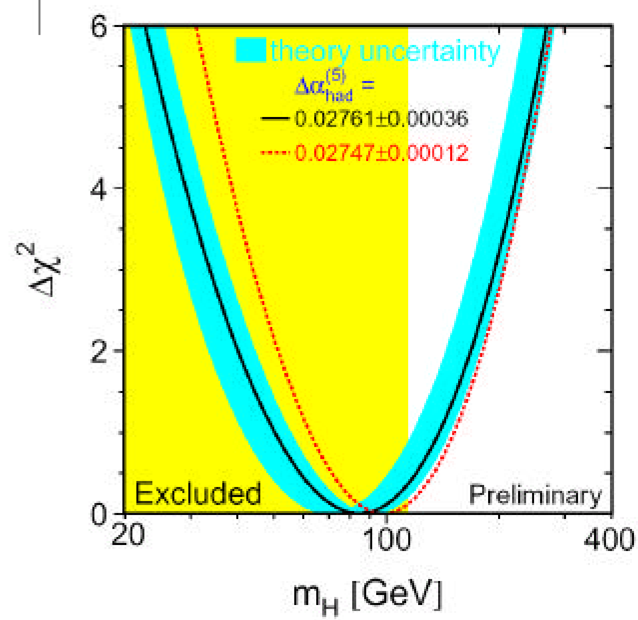
Where are we today?









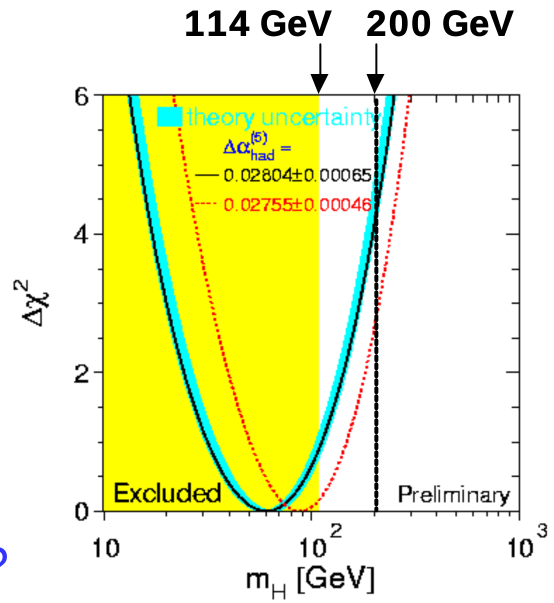
No sign of physics beyond SM yet experimentally !!!

Most important goal in next years.

BUT: Strong suggestions that Higgs is light ~115-200 Gev/c^2

Searching for the Higgs: history

- Over the last decade, the focus has been on experiments at the LEP e^+e^- collider at CERN
  - precision measurements of parameters of the *W* and *Z* bosons, combined with Fermilab's top quark mass measurements, set an upper limit of $m_H \sim 200$ GeV
  - direct searches for Higgs production exclude $m_H < 114$ GeV

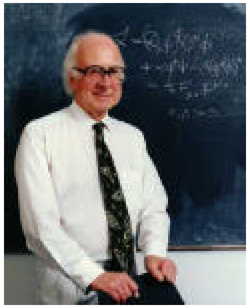


- Autumn 2000 & Spring 2001: Hints of a Higgs?
  - the LEP data may be giving some indication of a Higgs with mass 115 GeV (right at the limit of sensitivity)
  - despite these hints, CERN management decided to shut off LEP operations in order to expedite construction of the LHC

"The resolution of this puzzle is now left to Fermilab's Tevatron and the LHC."

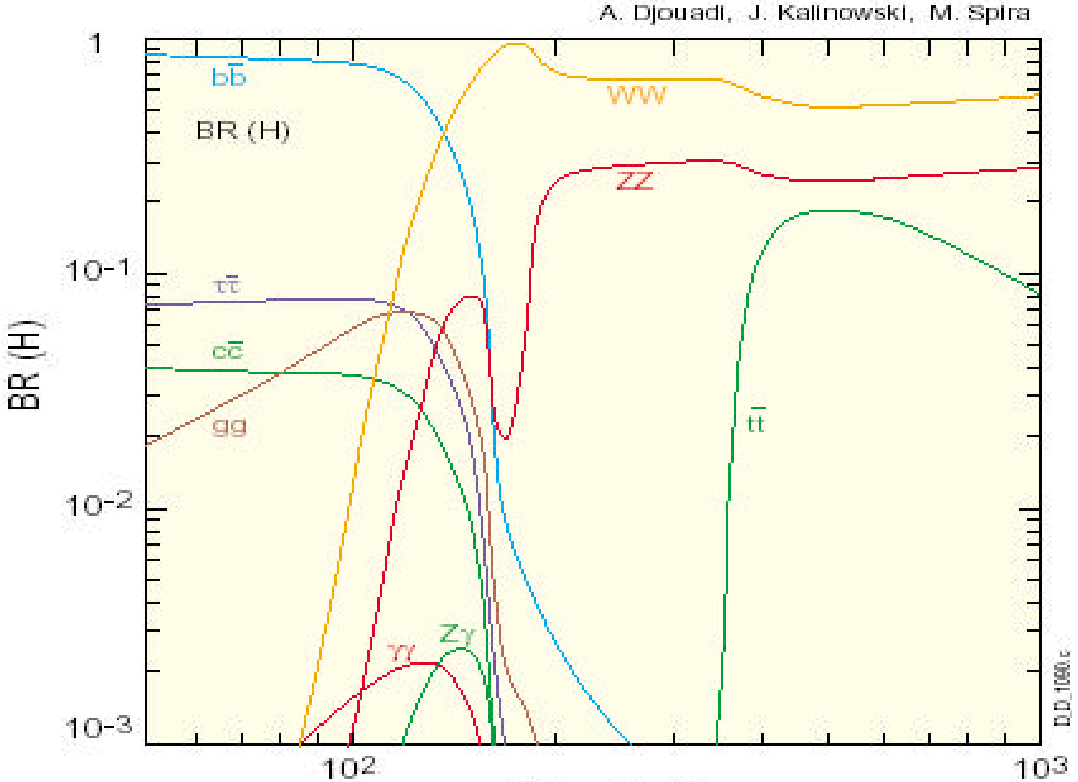
– Luciano Maiani

Higgs decay modes



One Higgs

- The only unknown parameter of the SM Higgs sector is the mass
- For any given Higgs mass, the production cross section and decays are all calculable within the Standard Model



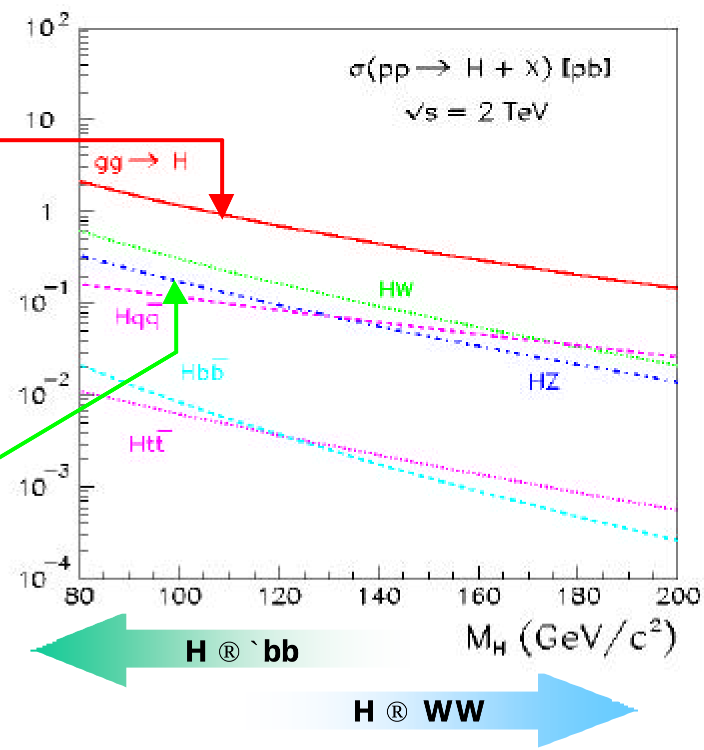
H ® `bb

H ® WW

Higgs Production at the Tevatron

- Inclusive Higgs cross section is quite high: ~ 1pb
  - for masses below ~ 140 GeV, the dominant decay mode H → bb is swamped by background
  - at higher masses, can use inclusive production plus WW decays

- The best bet below ~ 140 GeV appears to be associated production of H plus a W or Z
  - leptonic decays of W/Z help give the needed background rejection
  - cross section ~ 0.2 pb

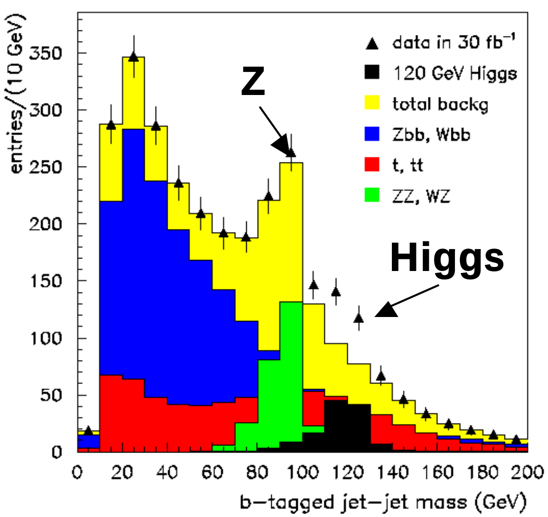


Dominant decay mode

$m_H < 140$ GeV: $H \to \bar{b}b$

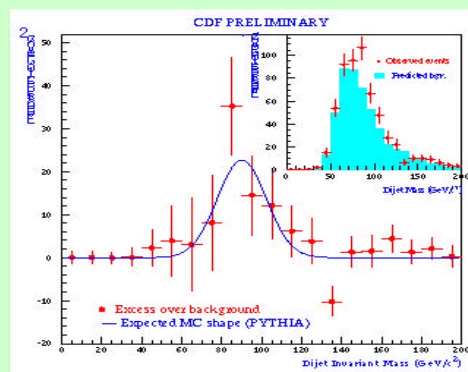
- $WH \to \bar{q}q' \, \bar{b}b$ is the dominant decay mode but is overwhelmed by QCD background
- $WH \to l^{\pm}\nu \, \bar{b}b$ backgrounds $W\bar{b}b$, WZ, $\bar{t}t$, single top
- $ZH \to l^{+}l^{-} \, \bar{b}b$ backgrounds $Z\bar{b}b$, ZZ, $\bar{t}t$
- $ZH \to \nu\nu \, \bar{b}b$ backgrounds QCD, $Z\bar{b}b$, ZZ, $\bar{t}t$
  - powerful but requires relatively soft missing E_T trigger (~ 35 GeV)

m_H = 120 GeV

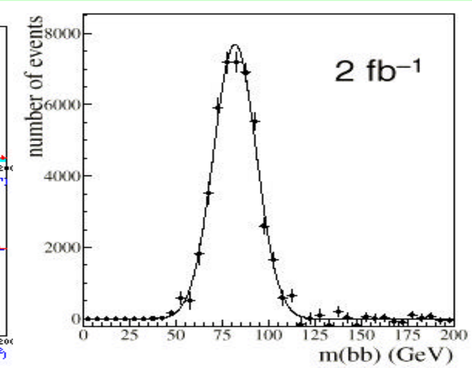


2 ´ 15fb^{-1} (2 experiments)

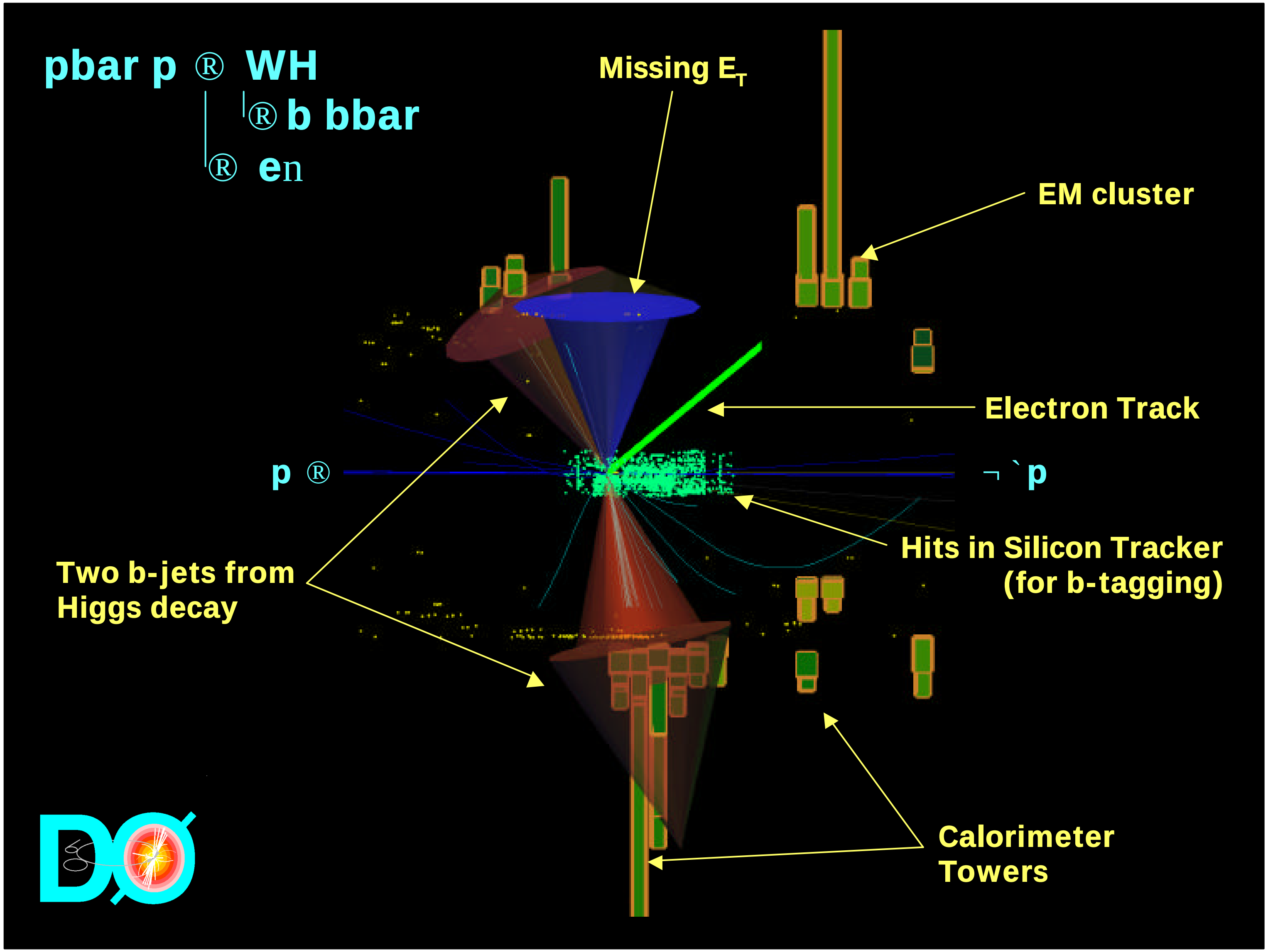
<u>`bb mass resolution</u>
Directly influences signal significance
Z ® `bb will be a calibration



CDF Z ® `bb in Run I



DØ simulation for 2fb^{-1}


pbar p ® WH
® b bbar
® en
Missing E_T
EM cluster
Electron Track
p ®
¬ ` p
Hits in Silicon Tracker
(for b-tagging)
Two b-jets from
Higgs decay
Calorimeter
Towers

Example: m_H = 115 GeV

- ~ 2 fb^{-1}/expt (2004): exclude at 95% CL
- ~ 5 fb^{-1}/expt (2005-6): evidence at 3σ level
- ~ 15 fb^{-1}/expt (2007-8): expect a 5σ signal

Every factor of two in luminosity yields a lot more physics

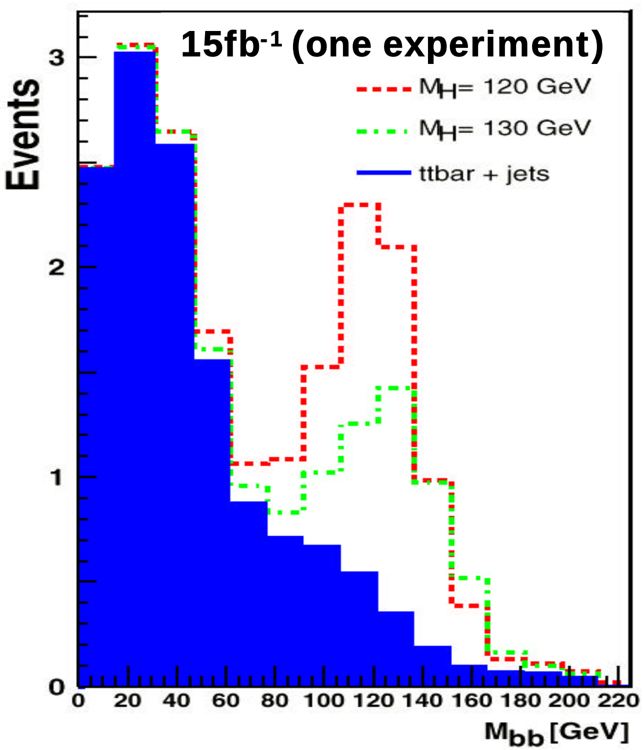
- Events in one experiment with 15 fb^{-1}:

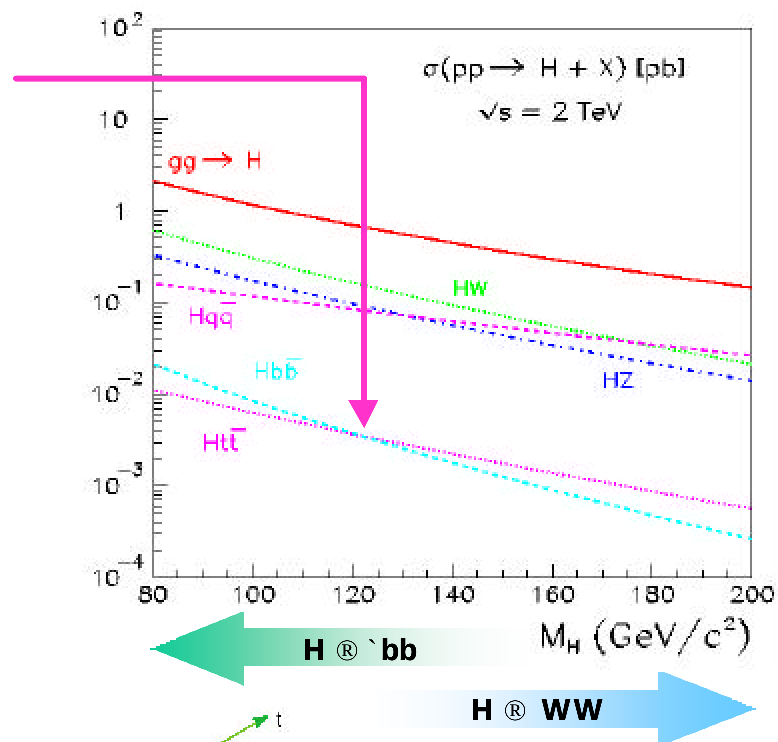
Mode	Signal	Background	$S/\sqrt{B}$
l νbb	92	450	4.3
ννbb	90	880	3.0
l l bb	10	44	1.5

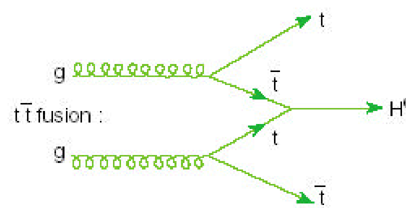
- If we do see something, we will want to test whether it is really a Higgs by measuring:
  - production cross section
  - Can we see H → WW? (Branching Ratio ~ 9% and rising w/ mass)
  - Can we see H → ττ? (Branching Ratio ~ 8% and falling w/ mass)
  - Can we see H→ γγ? (not detectable for SM Higgs at the Tevatron)

Associated production $t\bar{t}$ + Higgs

- Cross section very low (few fb) but signal: background good
- Major background is $t\bar{t}$ + jets
- Signal at the few event level:







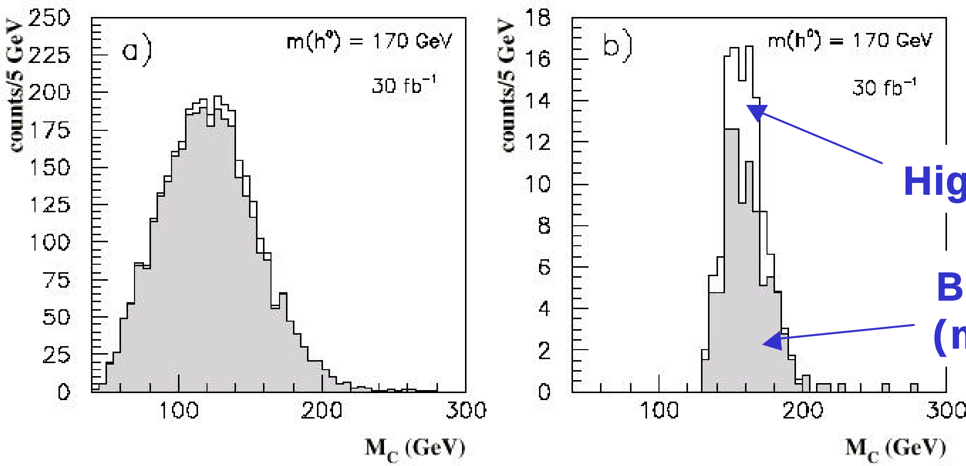
Tests top quark Yukawa coupling

$m_H > 140$ GeV : $H \to WW^{(*)}$

- $gg \to H \to WW^{(*)} \to l^+ l^- \nu\nu$

  Backgrounds Drell-Yan, WW, WZ, ZZ, $\bar{t}t$, tW, $\tau\tau$
  Initial signal:background ratio ~ 10^{-2}

  - Angular cuts to separate signal from "irreducible" WW background



2 ´ 15fb^{-1}
(2 experiments)

Higgs signal

Background (mainly WW)

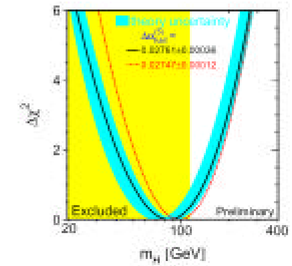
Before tight cuts: verify WW modeling

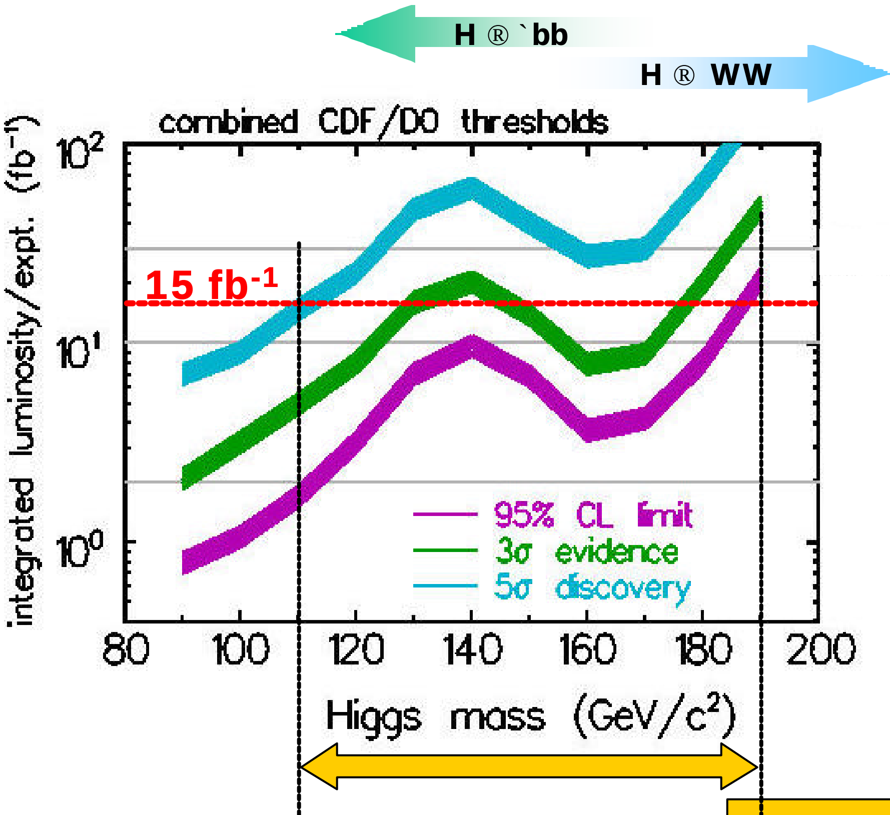
After tight cuts

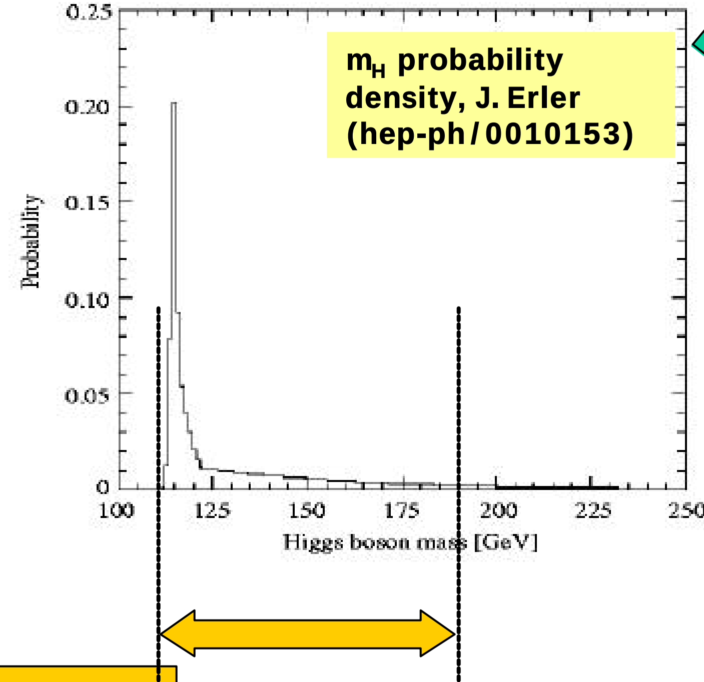
M_C = *cluster transverse mass* $= \sqrt{p_T^2(\ell\ell) + m^2(\ell\ell)} + \not{E}_T$

Tevatron Higgs mass reach

H.Weerts





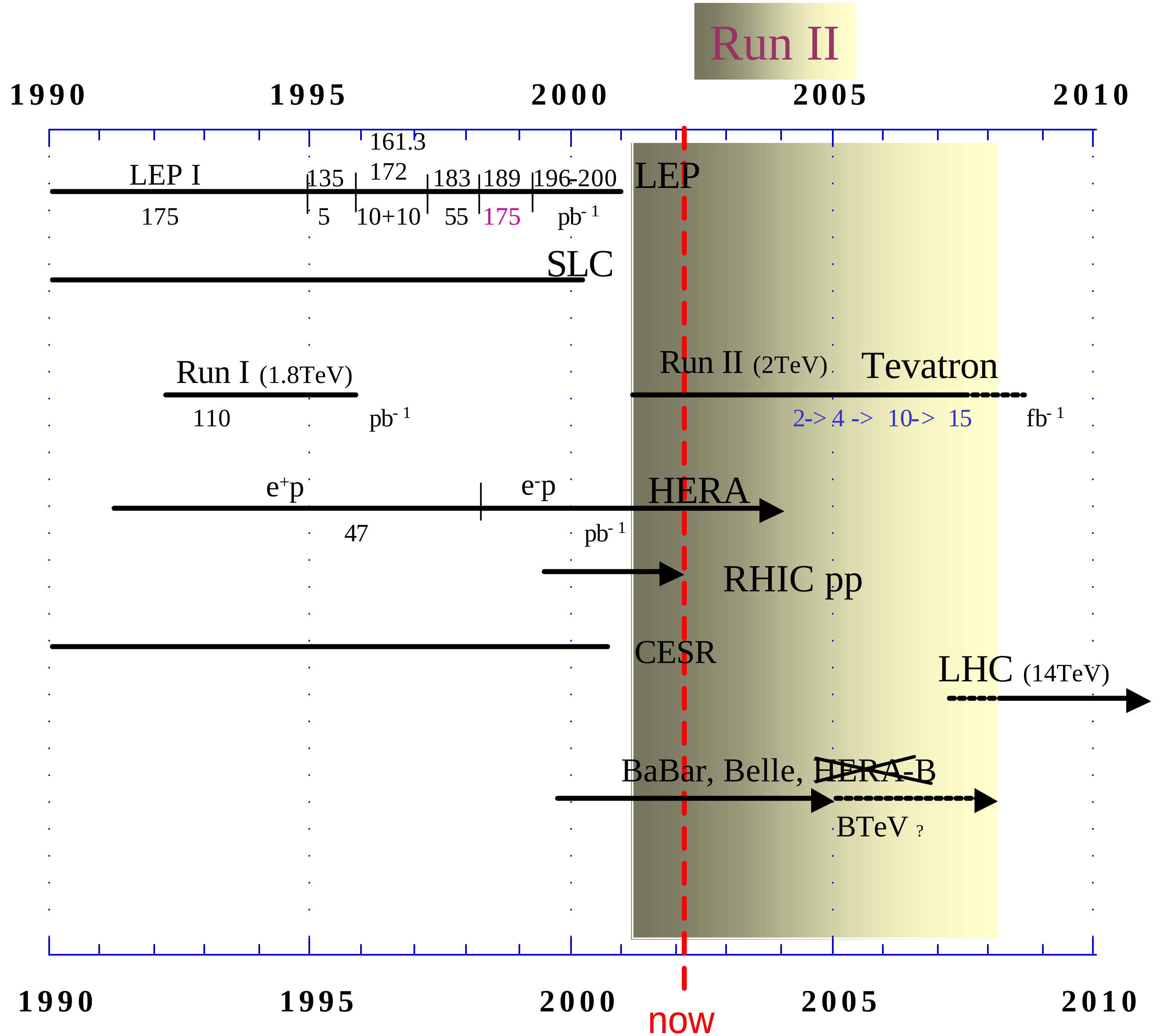


110-190 GeV

No guarantee of success, but certainly a most enticing possibility

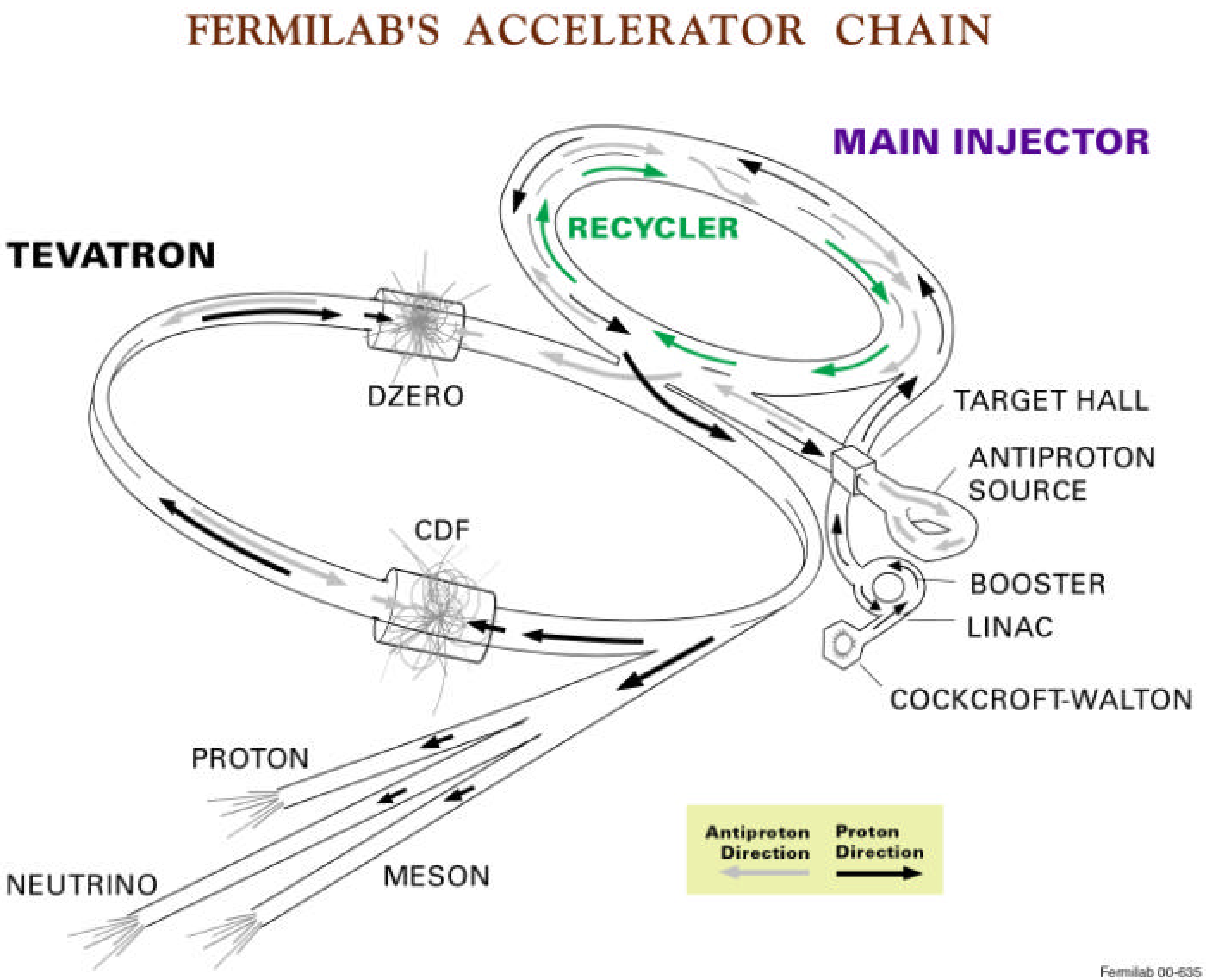
H.Weerts

Particle Physics accelerators

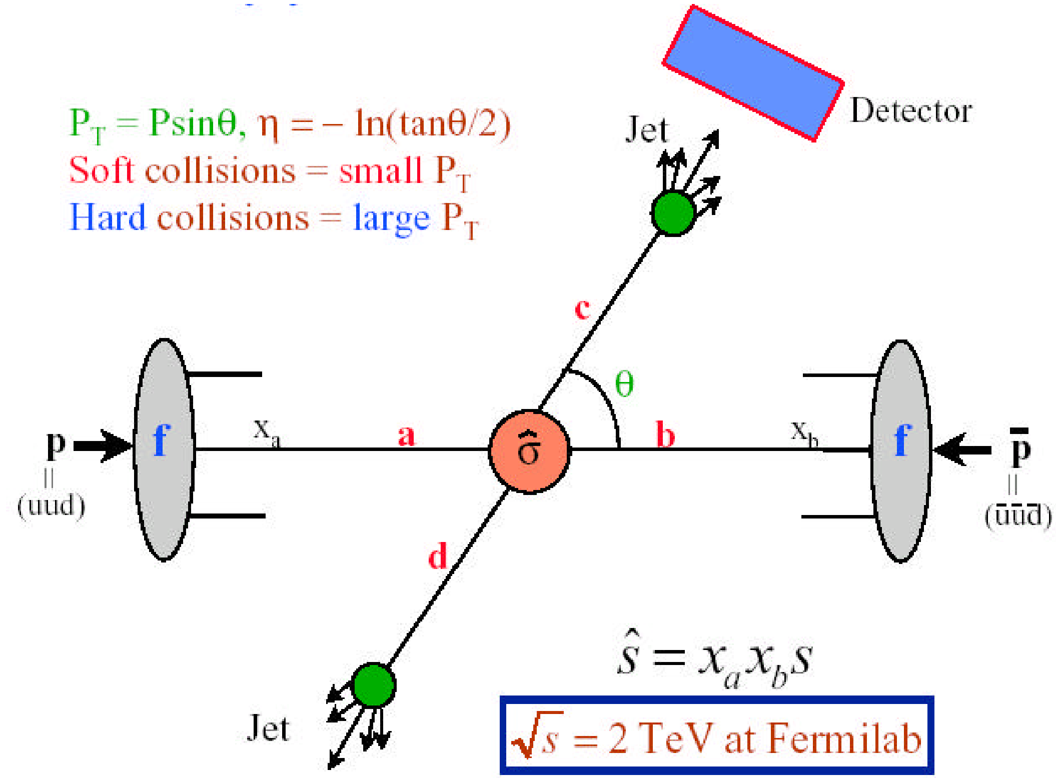


Mayaguez, March 2002

Accelerator Complex



$\bar{p}p$ interaction ts



- $f_{a/A}(x_a,\mu)$: Probability function to find a parton of type **a** inside hadron **A** with momentum fraction x_a - ***Parton Distribution Functions***

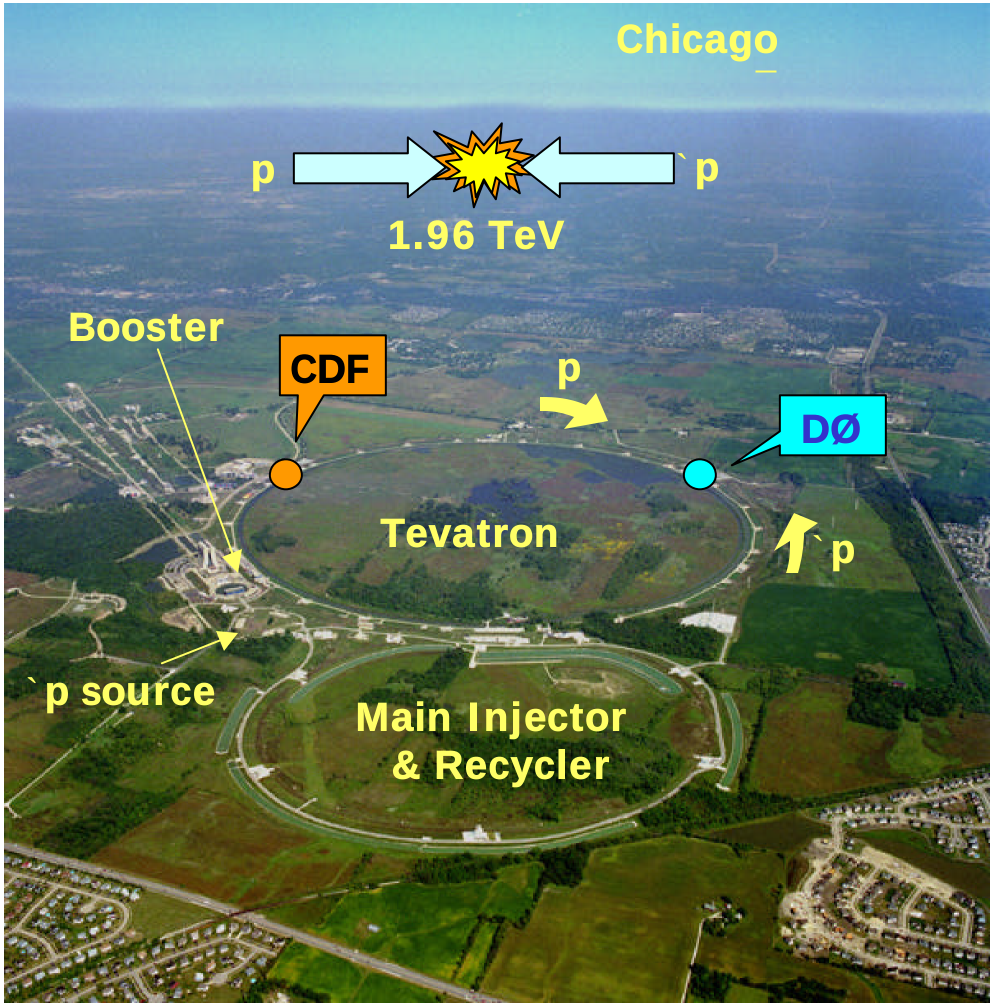
  x_a: Fraction of hadron's momentum carried by parton **a**

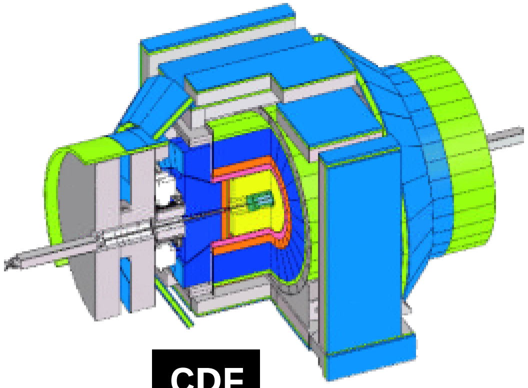
  μ: 4-momentum transfer related to the "scale" of the interaction

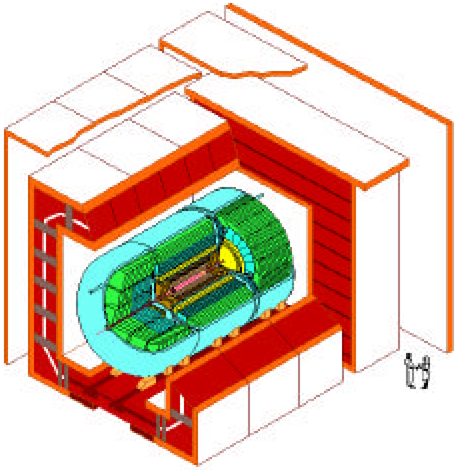
- $\hat{\sigma}$: Partonic level cross section

Need parton distributions

The Fermilab Tevatron Collider







DØ collaboration

DØ is an international collaboration of ~600 physicists from 18 nations who have designed, built and are operating a collider detector at the Tevatron

Collaboration continues to grow.....

Experimental physics opportunities limited in world

A flag missing ???

Some "standard" physics capabilities (bread & butter)

@ Tevatron

- QCD
  - jets at high E_T, photons, parton distributions & diffraction (FPD)
- Top physics
  - observe single top production
  - precise measurement of m_t
    - Δm_t = 2-3 GeV/expt with 2 fb^{-1}, ➔1-2 GeV with 15 fb^{-1}
- Electroweak
  - precise measurement of m_W
    - Δm_W = 40 MeV/expt with 2 fb^{-1}, ➔20 MeV with 15 fb^{-1}
  - Tri linear gauge couplings (*WW*, *W*γ, *WZ*, *Z*γ couplings)
- A comprehensive and powerful program of *B*-physics measurements
  - CP violation/CKM angles: sin2β
  - B_s mixing; expect to measure x_s ~ 30 in 2 fb^{-1}
  - Spectroscopy, lifetimes & rare decays
  - B cross section

mode	$J/y \to m^+m^-$	$J/y \to e^+e^-$
trigger eff. (%)	27	20
reco'd events	40,000	30,000
s (sin2b)	0.04	0.05
	0.03	

~ 2 fb^{-1}

Beyond the Standard Model searches

@ Tevatron

- Discovery reach for Tevatron for new physics (and compared to LHC)
  - SM Higgs:
    - Tevatron < 180 GeV LHC < 1 TeV
  - SUSY (squark/gluino masses)
    - Tevatron < 400-500 GeV LHC < 2 TeV
  - Extra Dimensions
    - Greater than 2-3TeV LHC much larger

Despite limited reach, the Tevatron is interesting because
both Higgs and SUSY "ought to be" light and within reach — and Tevatron has started.

Tevatron in Run 2

Tevatron upgrade:

- Increased energy
  1.8 TeV → 1.96 TeV
- Increased luminosity
  0.1 fb^{-1} → 2 fb^{-1} → 15 fb^{-1}
  (Run 1) (Run 2a) (Run 2b)

Detector upgrades:

- Higher event rates and backgrounds (electronics, DAQ, trigger)
- Considerable expansion of the physics capabilities

	Run 1b	Run 2a	Run 2b
#bunches	6x6	36x36	140x103
$\sqrt{s}$ (TeV)	1.8	1.96	1.96
typ L ($cm^{-2}s^{-1}$)	1.6×10^{30}	8.6×10^{31}	5.2×10^{32}
$\int$ Ldt (pb^{-1}/week)	3.2	17.3	105
bunch xing (ns)	3500	396	132
interactions/xing	2.5	2.3	4.8

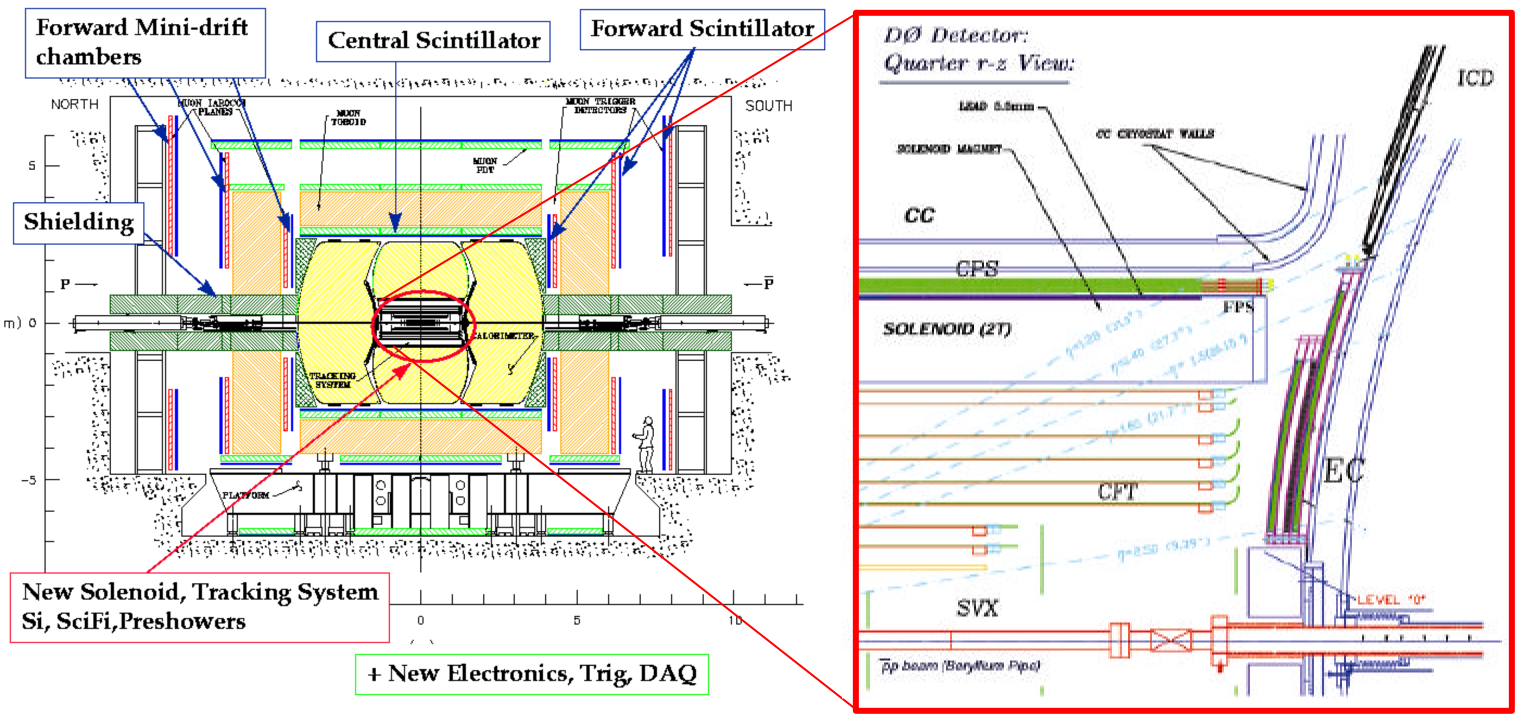
The Upgraded DØ Detector

Builds on the strengths of DØ:

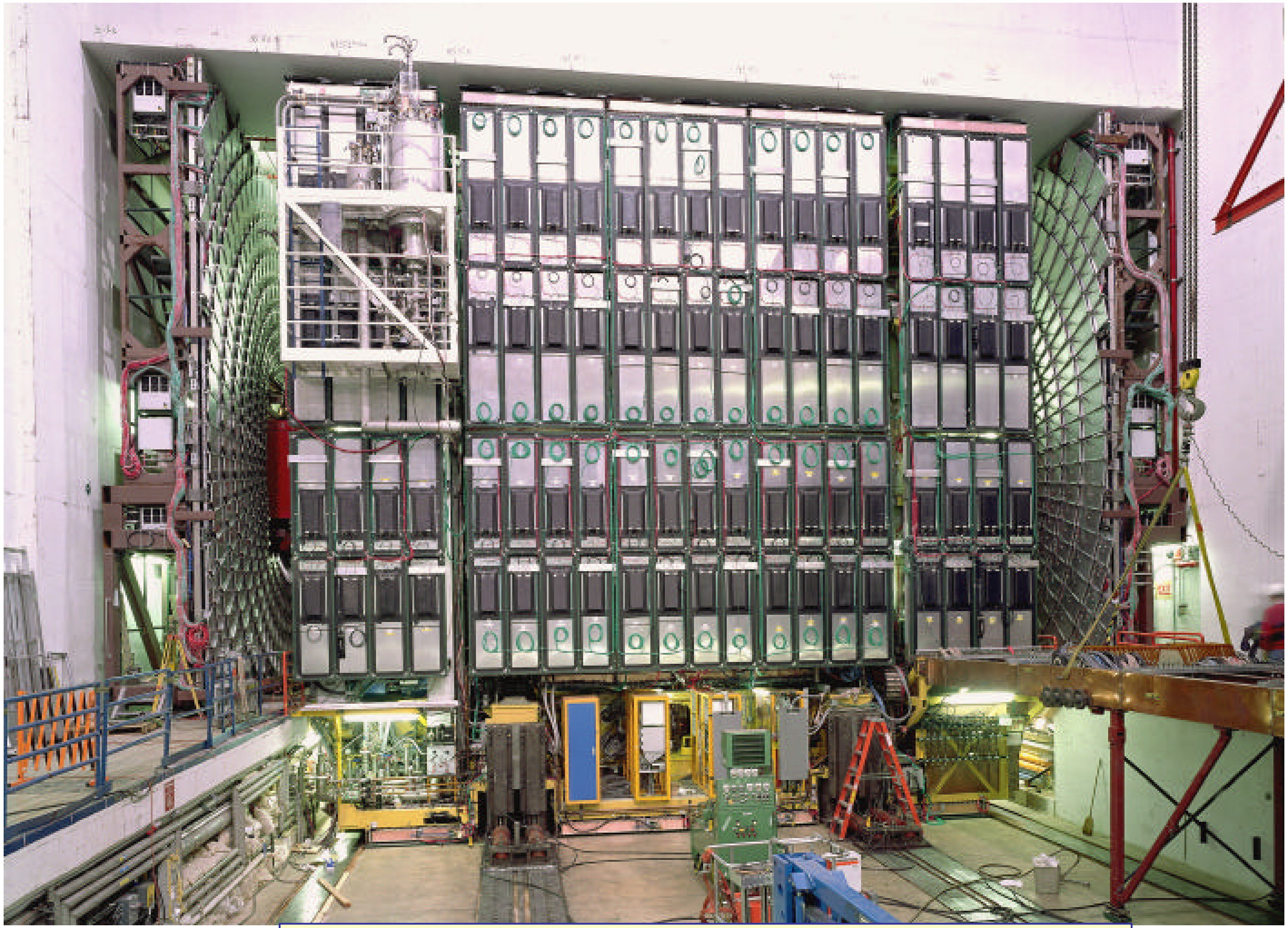
- Excellent calorimetry with faster readout
- Upgraded muon system for better m-ID

Augments its tracker and trigger capabilities:

- Inner tracking (silicon tracker, fiber tracker) with 2T superconducting solenoid
- Preshowers
- Pipelined 3-level trigger



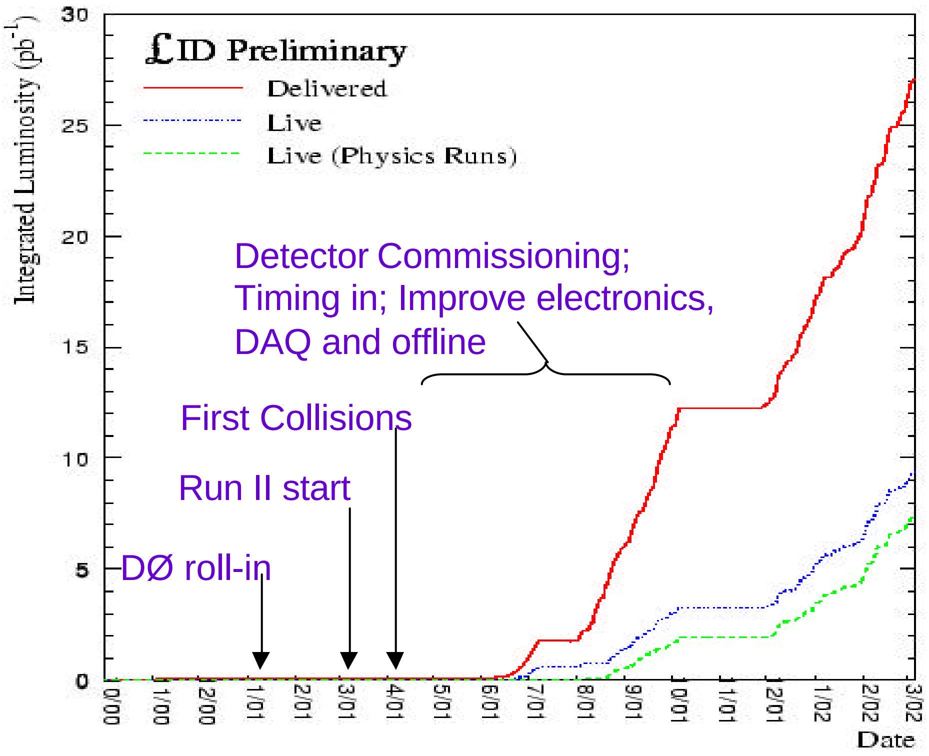
The Upgraded DØ Detector



Inside collision hall before putting the wall up

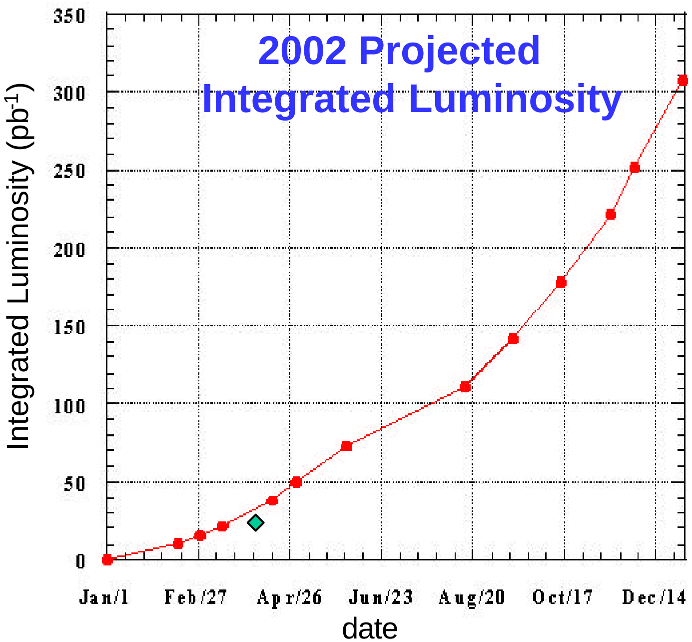
Run 2 in 2001 ....and 2002 plans

- Considerable fraction (~25%) of collected luminosity devoted to detector commissioning.
- Significant progress in identification of "physics objects": e, m, jets, electromagnetic and jet energy scales, etc.

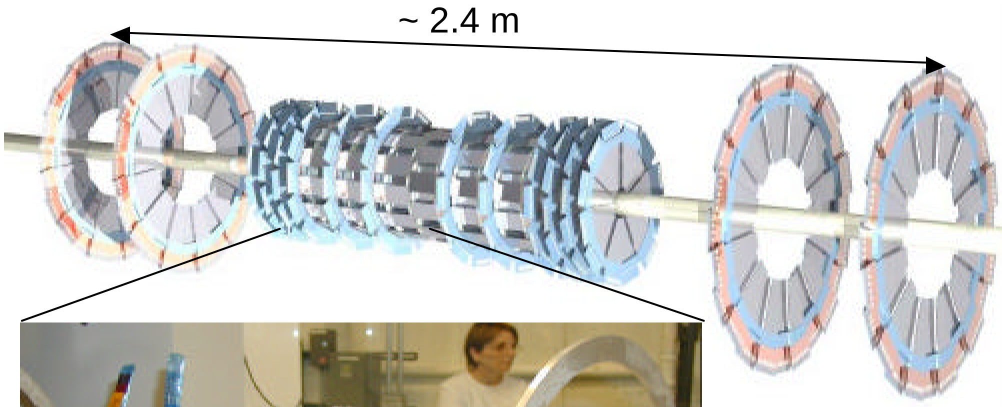


In the next few months:

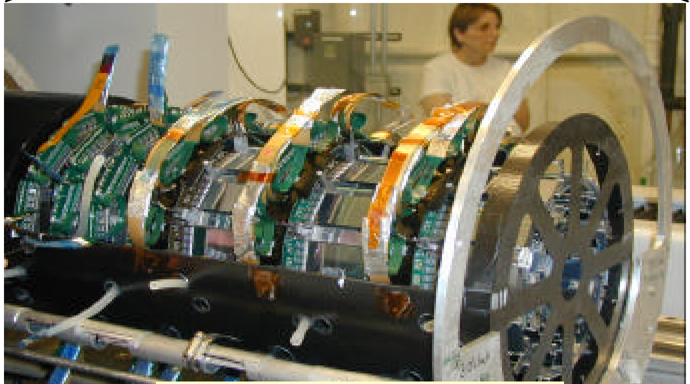
- Finish detector commissioning
- Complete triggers and improve DAQ
- Debugging, calibration, alignment
- Refine reconstruction algorithms
- ...
- Also looking forward to more integrated luminosity!!!



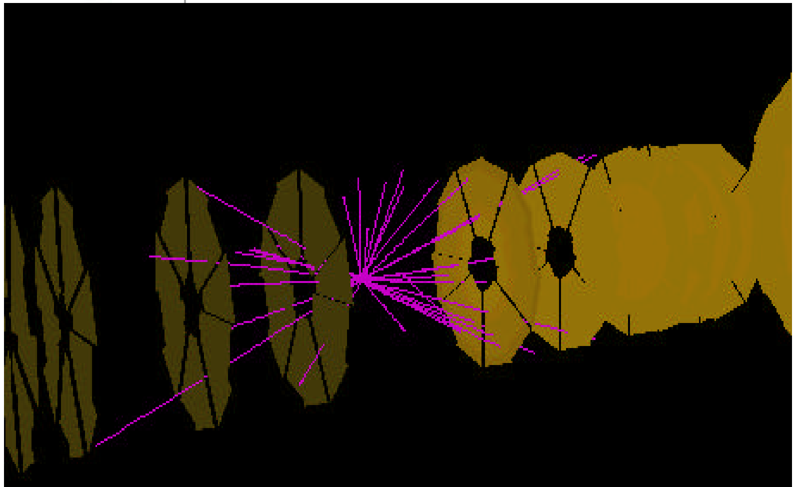
Silicon Microstrip Tracker (SMT)



- ~800,000 readout channels
- 6 barrels (4 layers) with interspersed (F-)disks
- 4 external large area (H-)disks for forward tracking (2 < |η| < 3)
- Single (axial) and double sided (axial+stereo) detectors
- 3D track reconstruction capabilities



SMT half cylinder



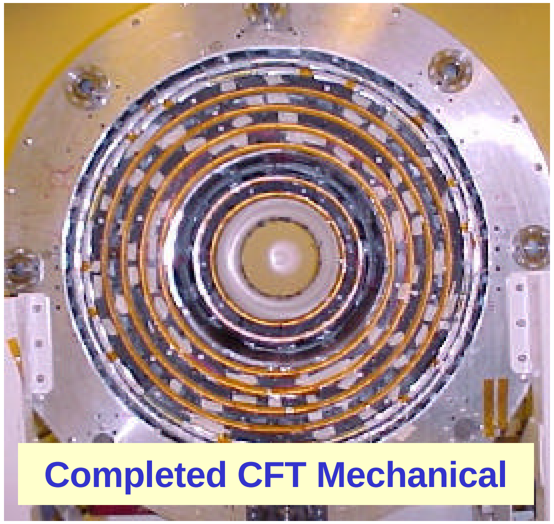
Primary Vertex with SMT Tracking

<u>100% commissioned</u>

Barrels: 95.2% operational
F-disks: 95.8% operational
H-disks: 86.5% operational

Central Fiber Tracker (CFT)

- 20 cm < r < 51 cm
- 8 layers of axial and stereo 830 mm ∅ scintillating fibers
- ~12m long clear wave-guide to Visible Light Photon Counter (VLPC)
    - 9K operating temperature
    - 85% QE, excellent S/N
- ~77k readout channels
- Fast pick-off for trigger

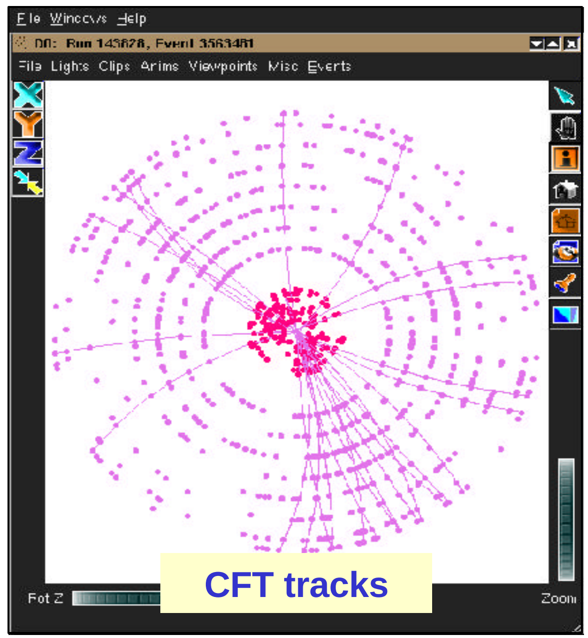


Completed CFT Mechanical

axial: 100% readout

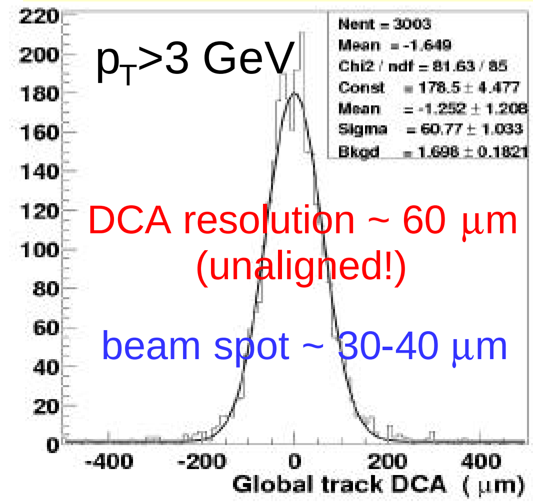
stereo: 52% readout

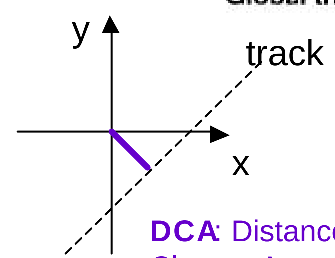
Fully commissioned by mid-April



CFT tracks

(SMT+CFT) Global tracks





DCA: Distance of Closest Approach

Calorimeter

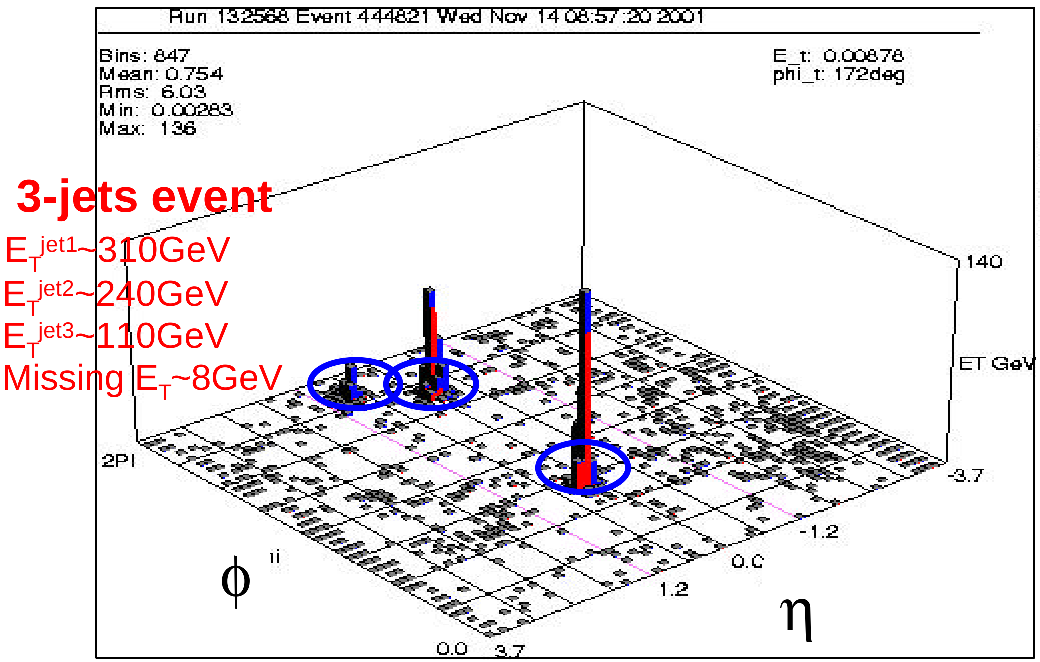
Preserve excellent Run 1 calorimetry:

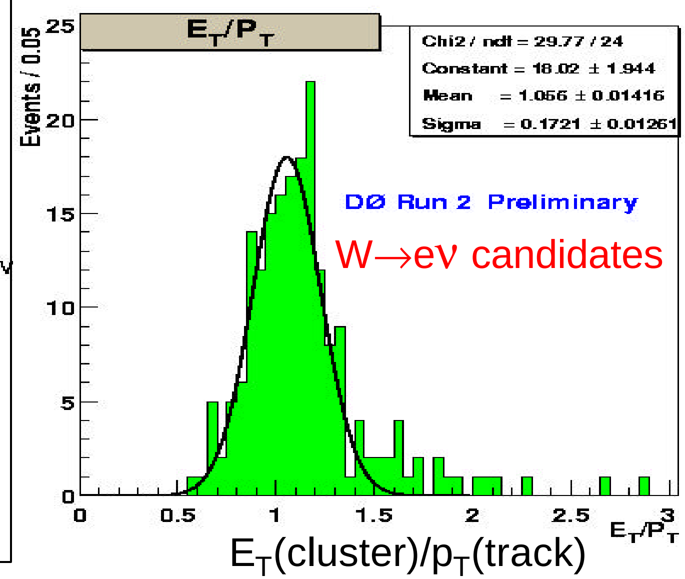
- LAr sampling: stable, uniform response, rad. hard., fine spatial segmentation
- U absorber (Cu/Steel for coarse hadronic)
- Uniform, hermetic, full coverage ($|\eta| < 4.2$)
- Compensating (e/p~1)
- Good energy resolution

... and upgrade electronics:

- Reduced bunch spacing
- L1 trigger
- Preserve noise performance

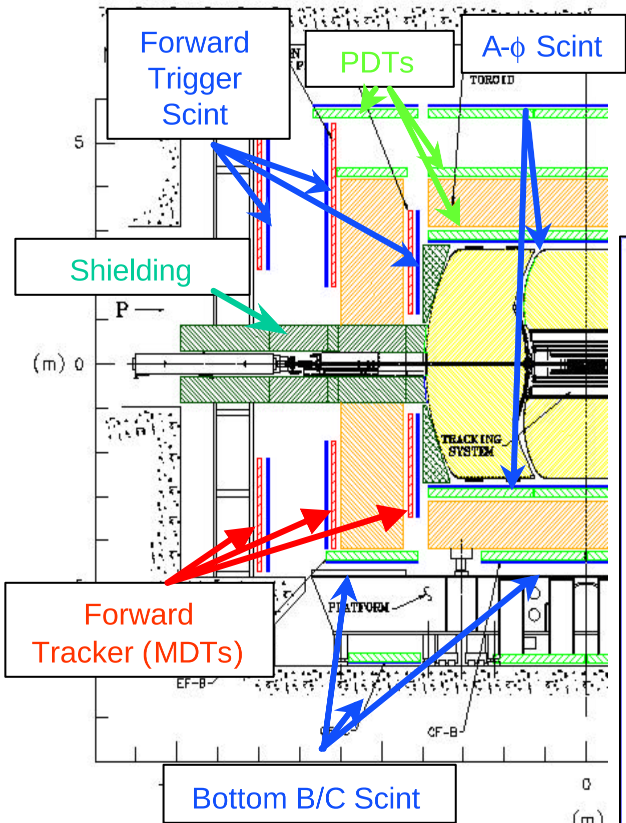
100% commissioned
~55K readout channels
~0.1% dead/noisy

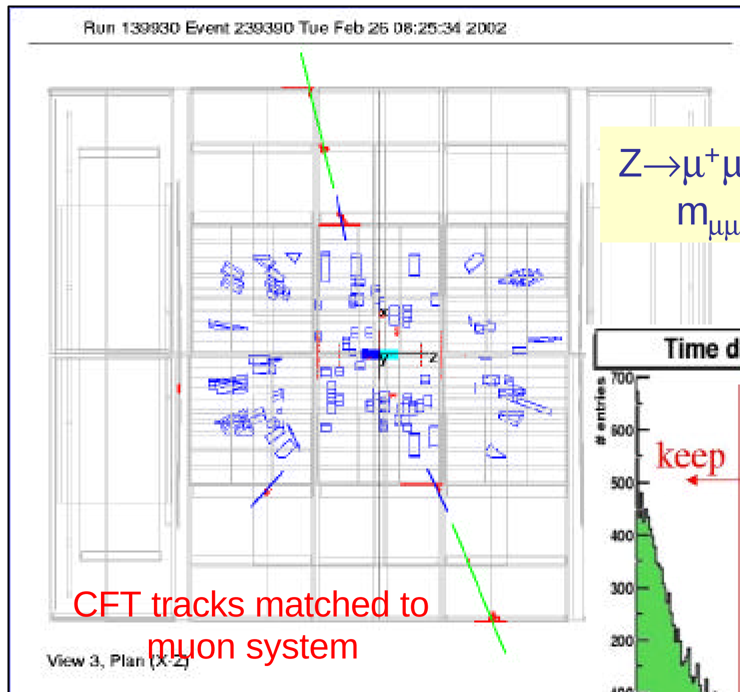


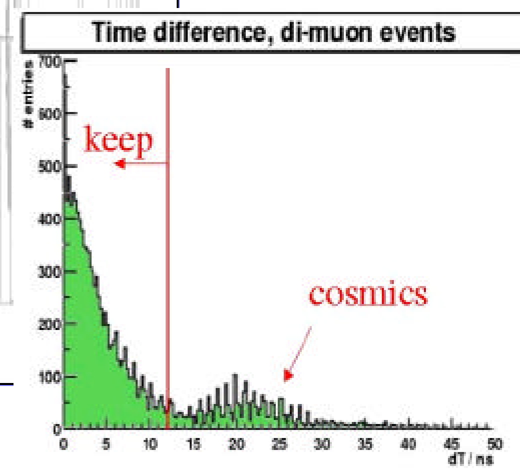


Muon System

- Coverage to $|\eta|<2$
- Emphasize m-ID at all trigger levels
- Momentum determination not precise (use inner tracking)
- Good time resolution (~2.5 ns) of trigger scintillators to remove out-of-time background (cosmics)



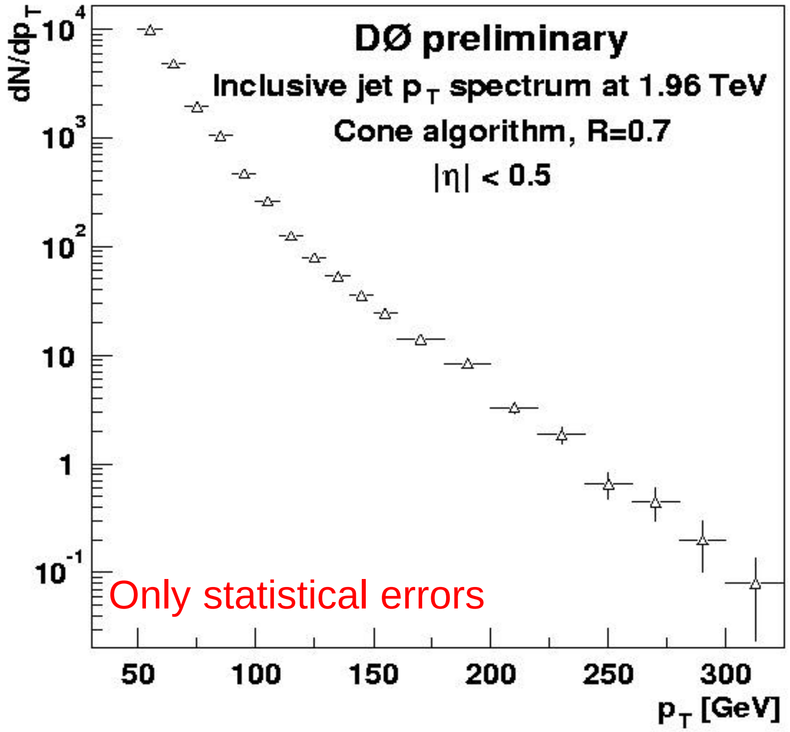


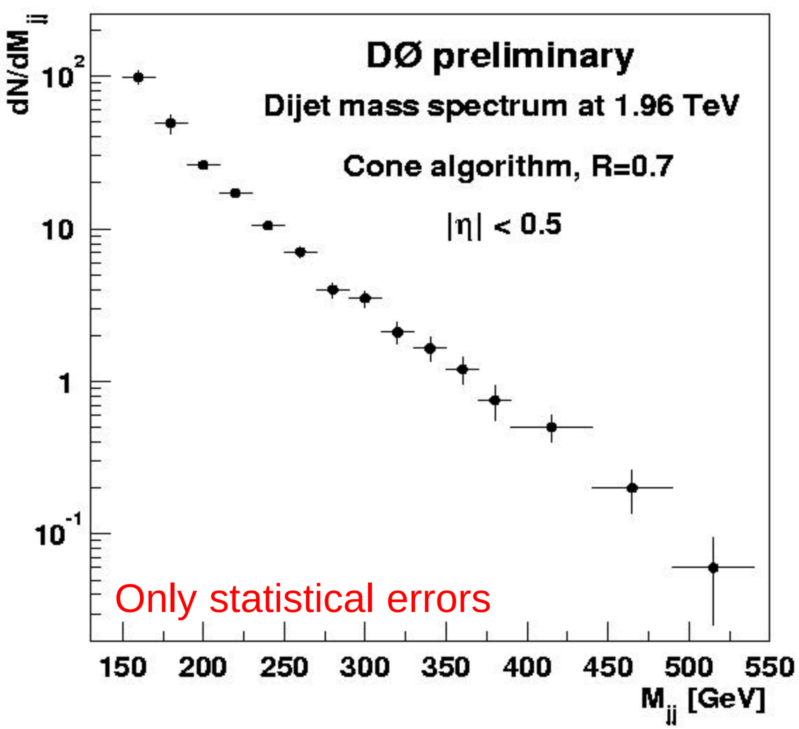


100% commissioned

QCD physics

- Integrated luminosity: ~1 pb^{-1}

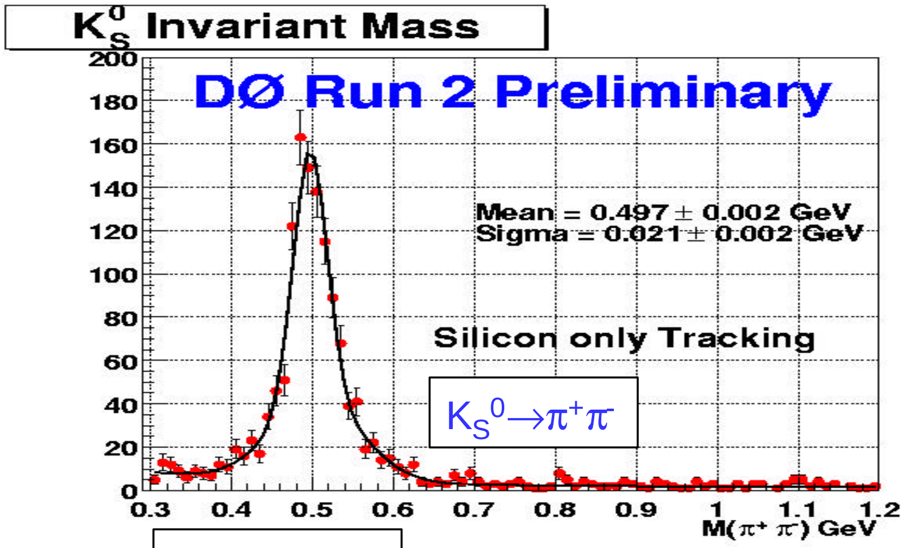




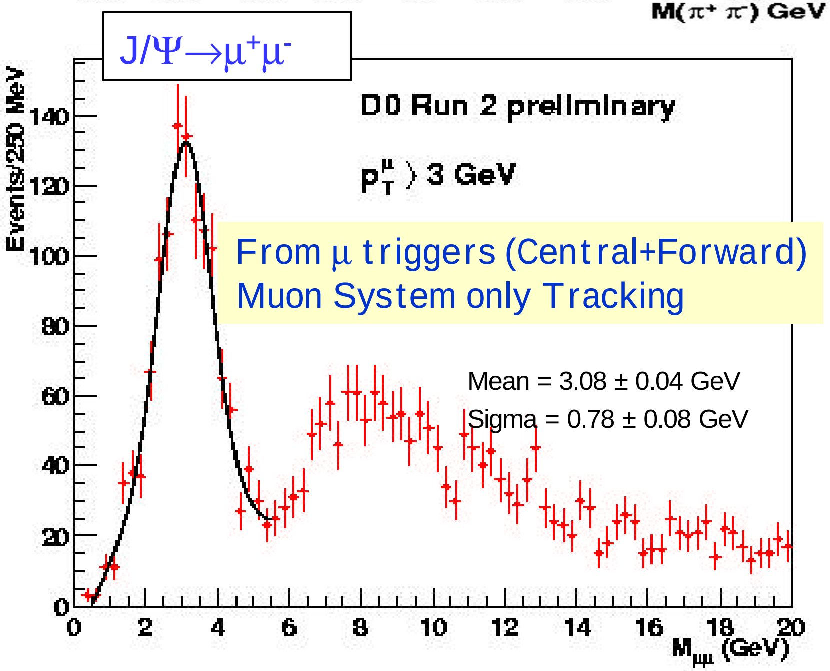
- Not fully corrected distributions:
  - Preliminary correction for jet energy scale (but no unsmearing of resolution effects)
  - No correction for trigger (small kinks) or selection efficiencies

Different trigger match up, based on luminosity information

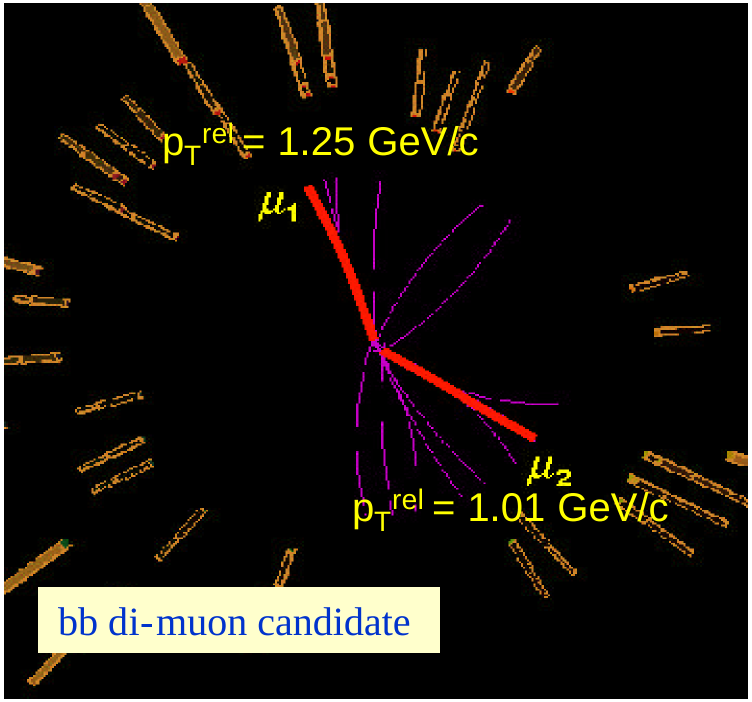
B physics



K_S^0 Invariant Mass
DØ Run 2 Preliminary
Mean = 0.497 ± 0.002 GeV
Sigma = 0.021 ± 0.002 GeV
Silicon only Tracking
$K_S^0 \to \pi^+\pi^-$
$M(\pi^+\pi^-)$ GeV



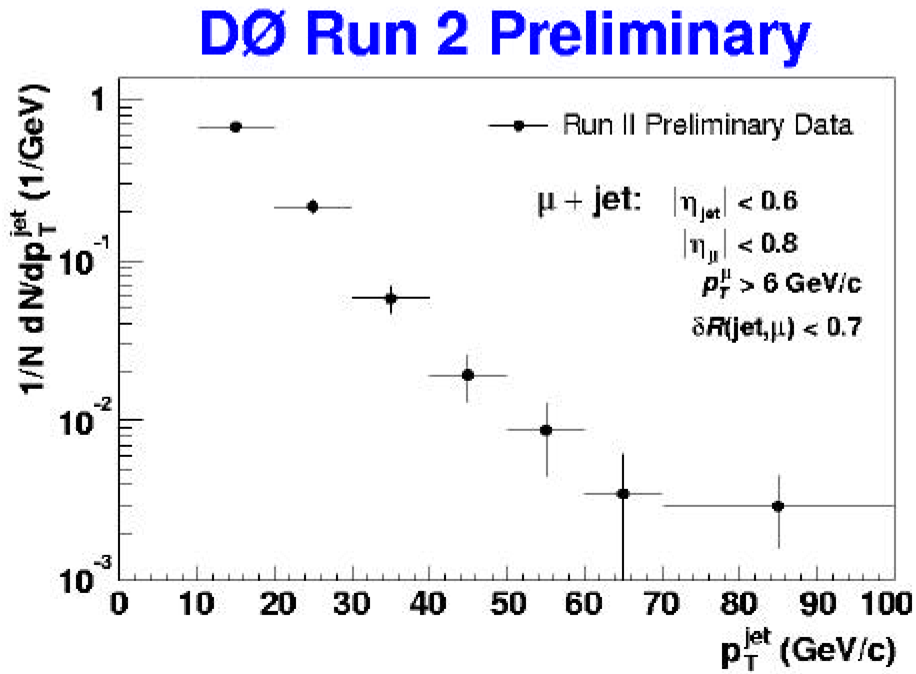
$J/\Psi \to \mu^+\mu^-$
D0 Run 2 preliminary
p_T^μ > 3 GeV
From μ triggers (Central+Forward)
Muon System only Tracking
Mean = 3.08 ± 0.04 GeV
Sigma = 0.78 ± 0.08 GeV
Events/250 MeV
$M_{\mu\mu}$ (GeV)



p_T^{rel} = 1.25 GeV/c
μ_1
μ_2
p_T^{rel} = 1.01 GeV/c
bb di-muon candidate

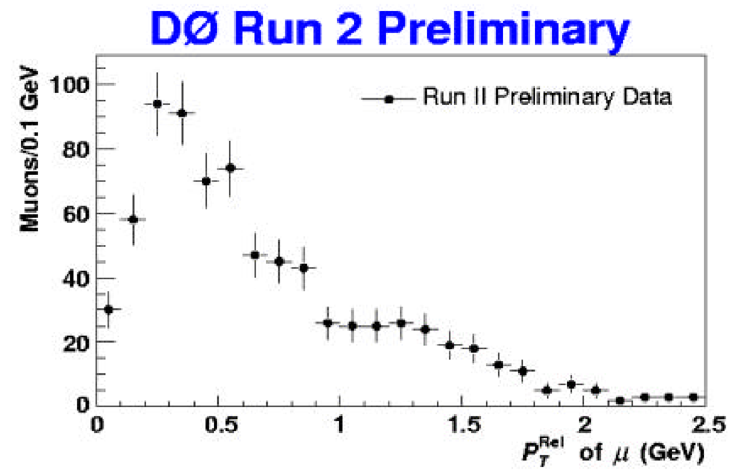
B physics cross sections

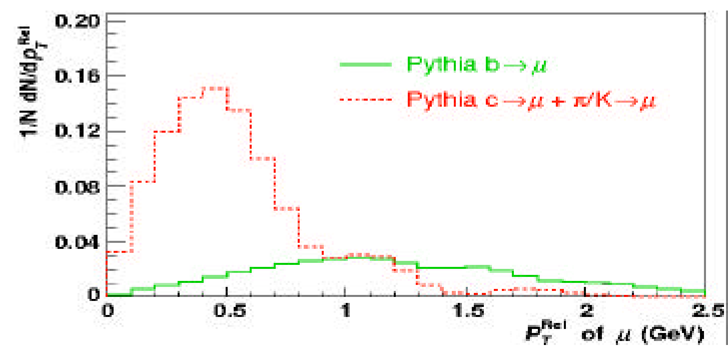
- Normalized μ+jet differential cross-section (data sample <0.2 pb^{-1}).
- Trigger and reconstruction efficiencies and jet energy scale corrections included.



➢ Consistent in shape with DØ Run I results in same kinematic region.

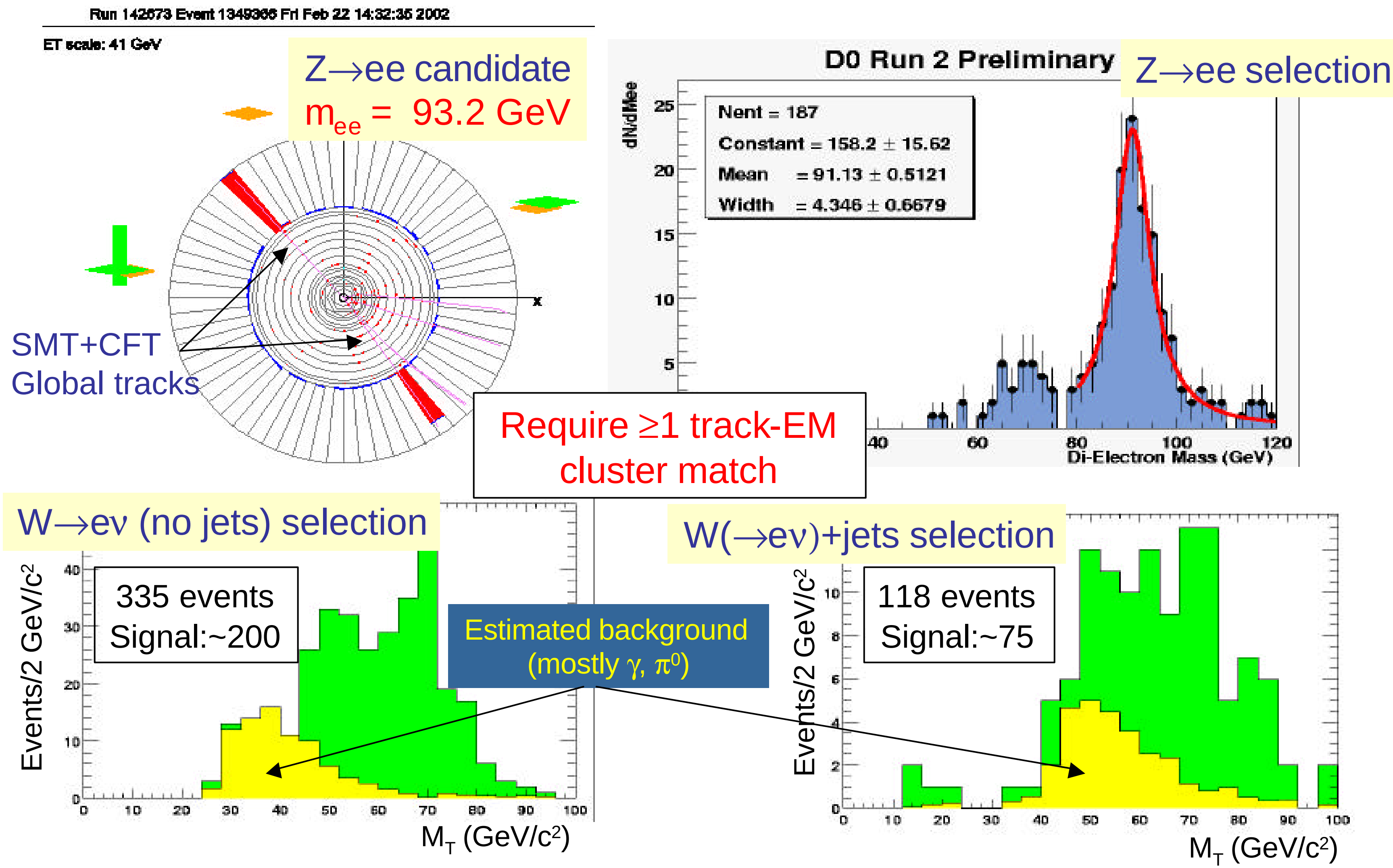
- Transverse momentum of the μ with respect to the jet axis is a good discriminant between direct b→μ and





➢ Evidence for the b-content in the μ+jet sample.

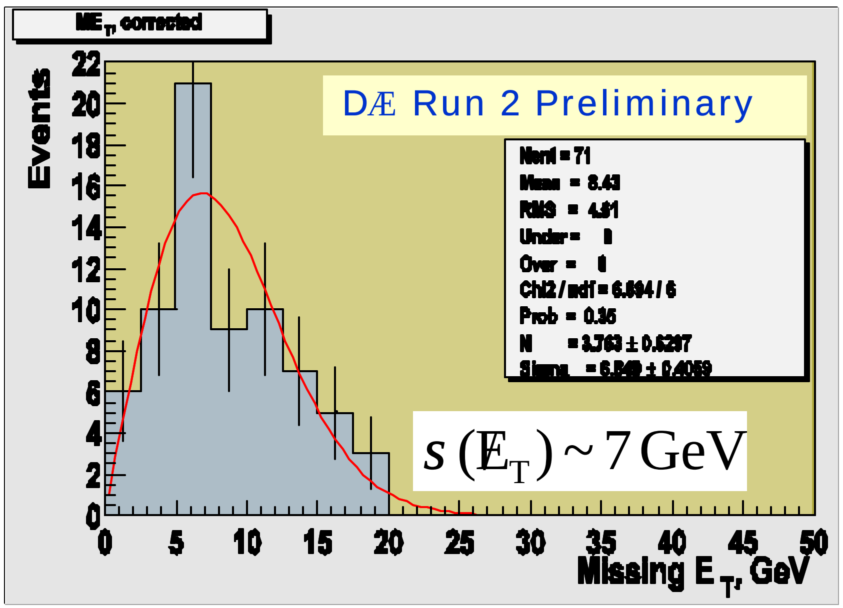
Electroweak physics (W/Z, Top, Higgs)



New Phenomena Physics

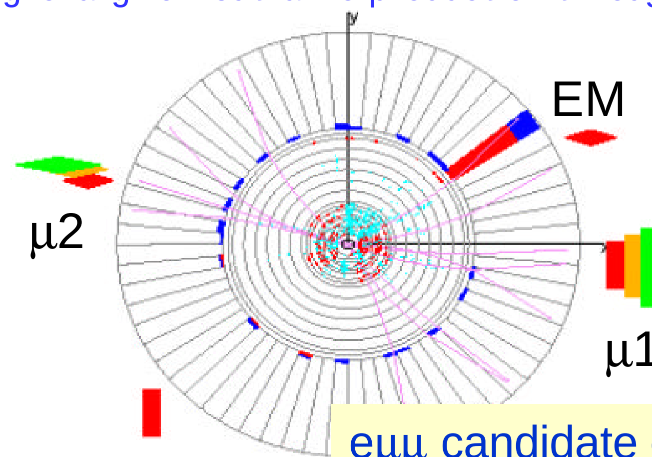
Di-EM+Missing E_T channel

- Important signature for new physics searches (SUSY, extra dimensions, etc).
- Determine ME_T resolution from inclusive di-electron sample w/ at least one track match.



Search for Trileptons

- Trilepton events are one of the cleanest signatures of SUSY (e.g. chargino+neutralino production through W*)

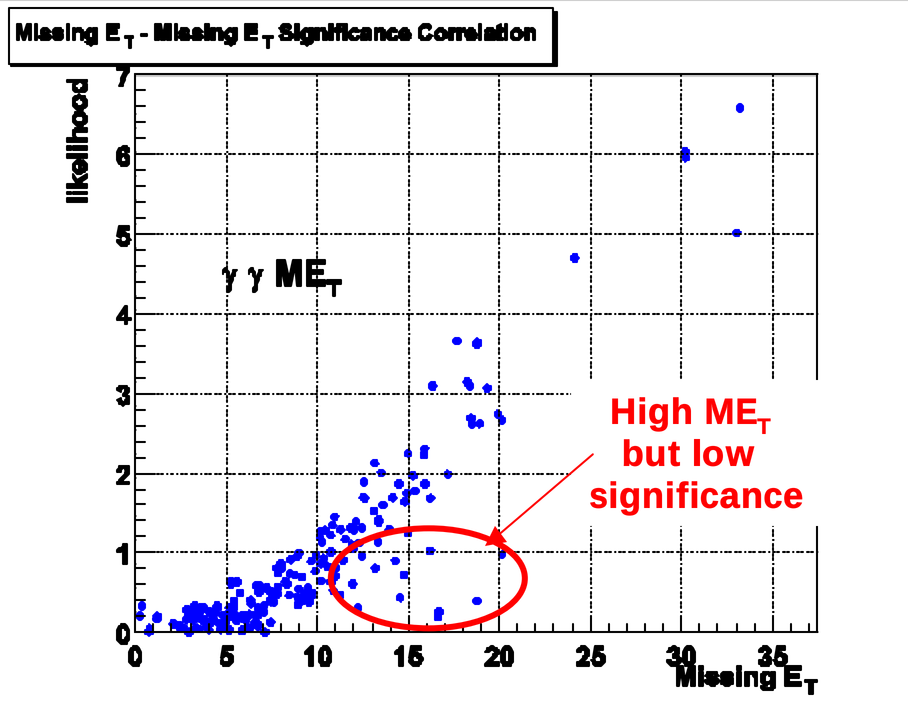


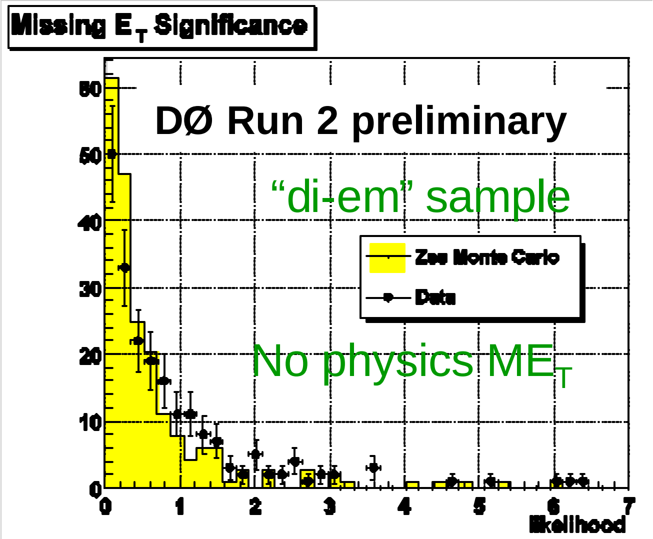
eμμ candidate event

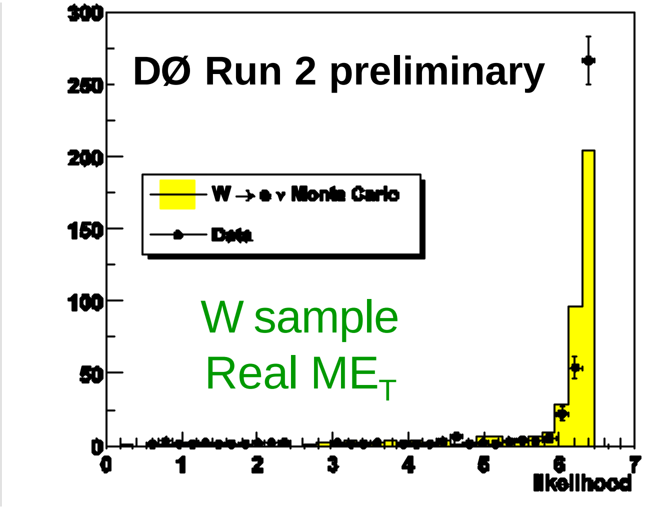
EM	μ1	μ2
E_T = 19.2 GeV η = 0.40 φ = 0.63 no track match	p_T = 28.2 GeV η = -0.10 φ = 6.20 charge = -1	p_T = 9.82 GeV η = -1.48 φ = 2.88 charge = 1
	$m_{\mu\mu}$ = 41.5 GeV	
	Missing E_T =31.8 GeV	

On the raod to SUSY: Understanding Missing E_T

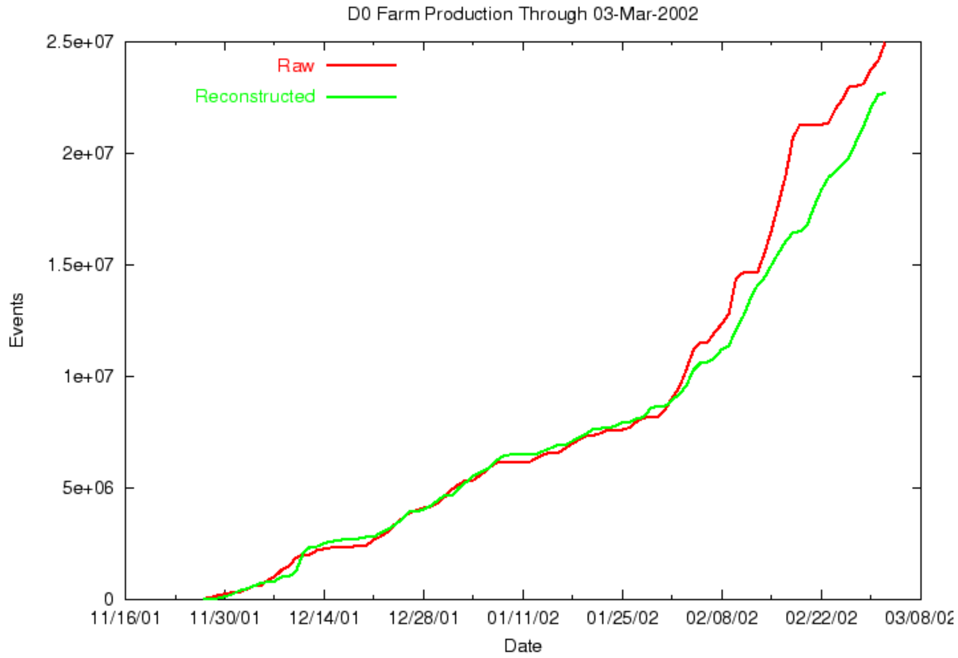
- Use ME_T significance to take into account event topology, found vertices, and known resolutions
  - Low significance – no physics ME_T
  - high significance - ME_T likely not due to mismeasurement
- Monte Carlo can reproduce distributions:







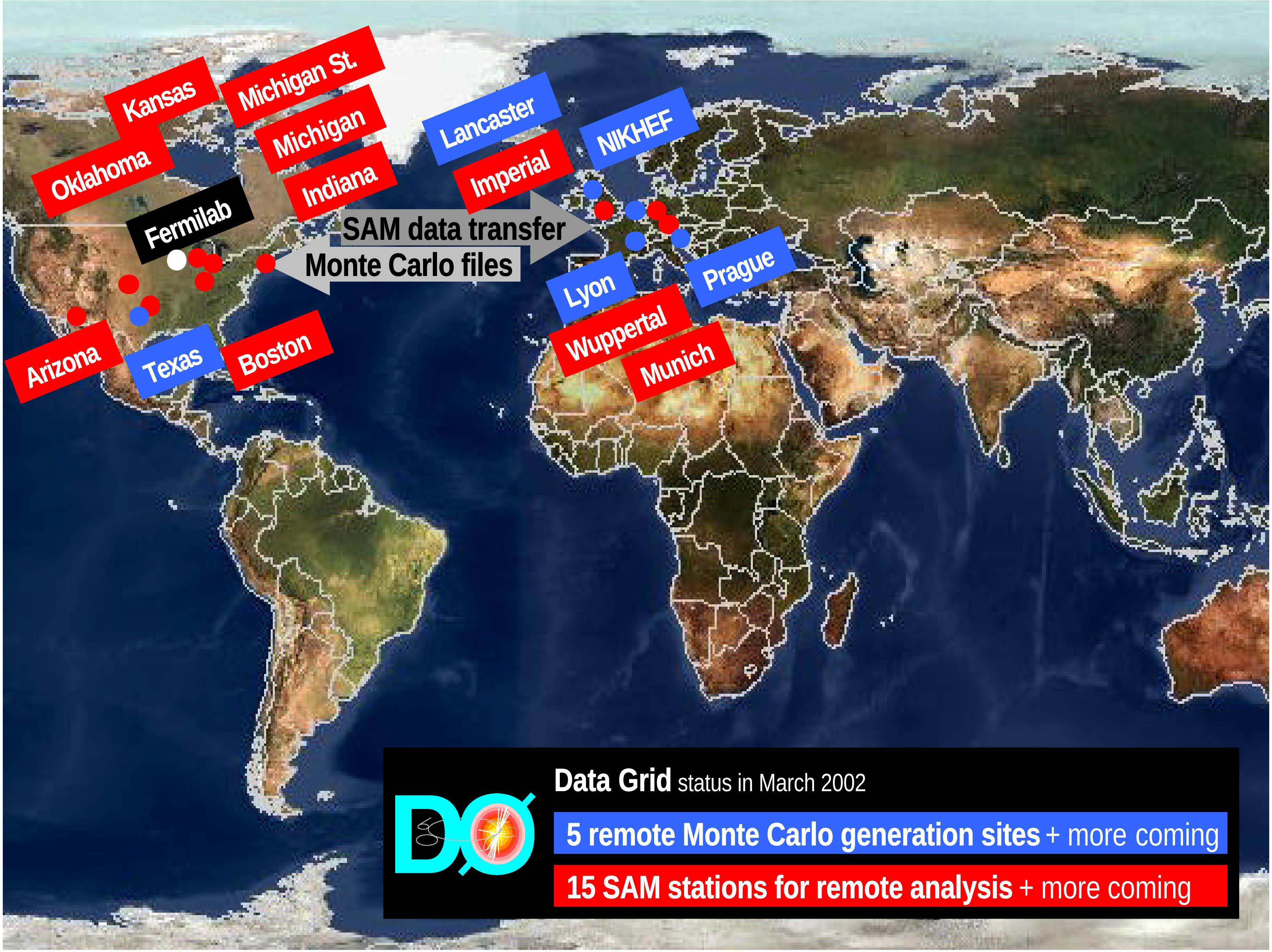
Offline processing

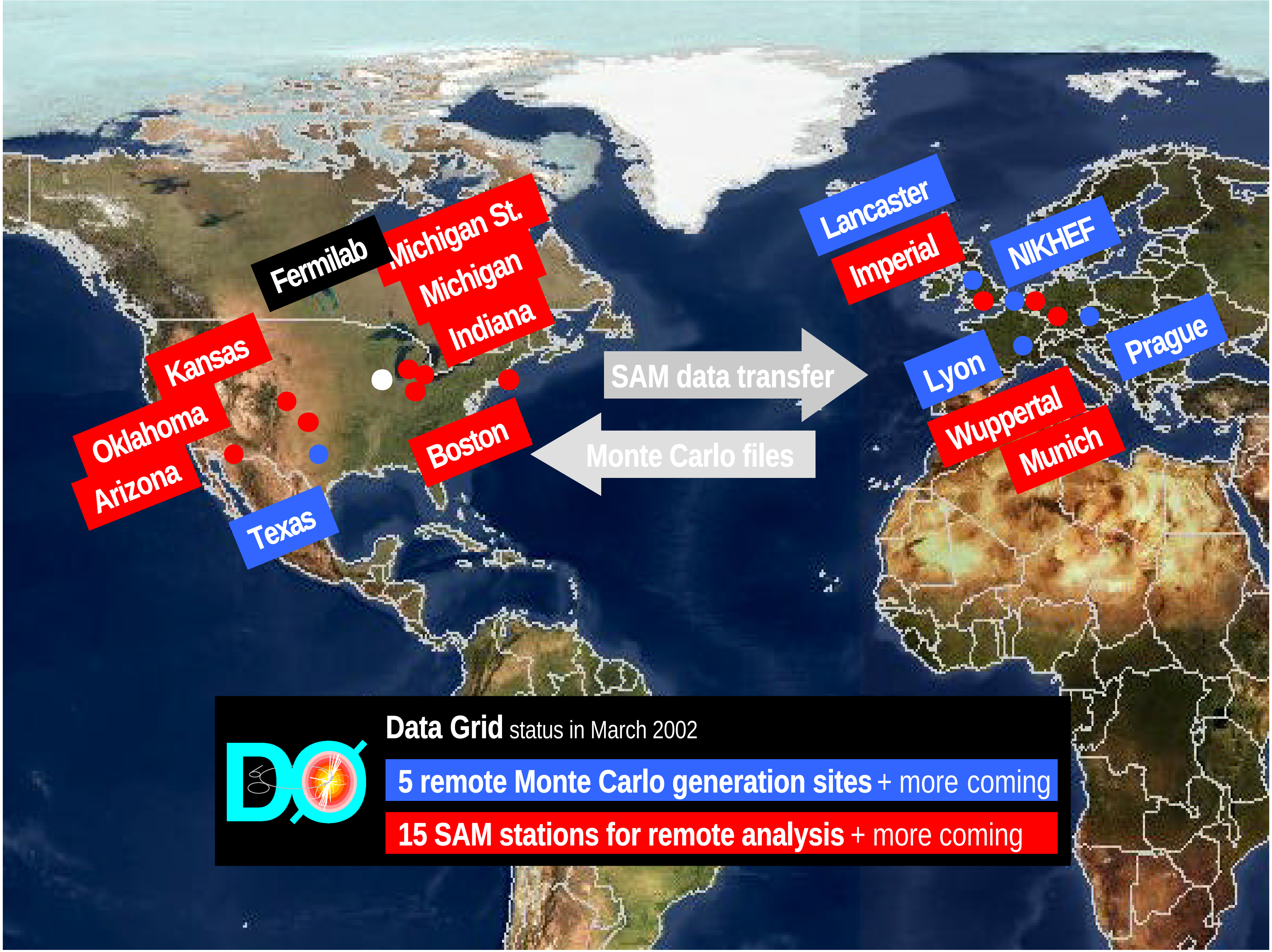


Offline processing of data keeps up with data taking.

Have even reconstructed large fraction of data with improved versions of offline reconstruction

- Extensive Monte Carlo farms offsite Fermilab, can be used for real data reconstruction
- First version of GRID has been put together in the form of our SAM (Sequential data Access via Metadata) which distributed across the world
- Putting in place capabilities for analysis from remote sites


Kansas
Michigan St.
Oklahoma
Michigan
Indiana
Fermilab
Lancaster
Imperial
NIKHEF
SAM data transfer
Monte Carlo files
Lyon
Prague
Wuppertal
Munich
Arizona
Texas
Boston
DØ
Data Grid status in March 2002
5 remote Monte Carlo generation sites + more coming
15 SAM stations for remote analysis + more coming



Fermilab
Michigan St.
Michigan
Indiana
Kansas
Oklahoma
Arizona
Texas
Boston
Lancaster
Imperial
NIKHEF
Prague
Lyon
Wuppertal
Munich
SAM data transfer
Monte Carlo files
Data Grid status in March 2002
5 remote Monte Carlo generation sites + more coming
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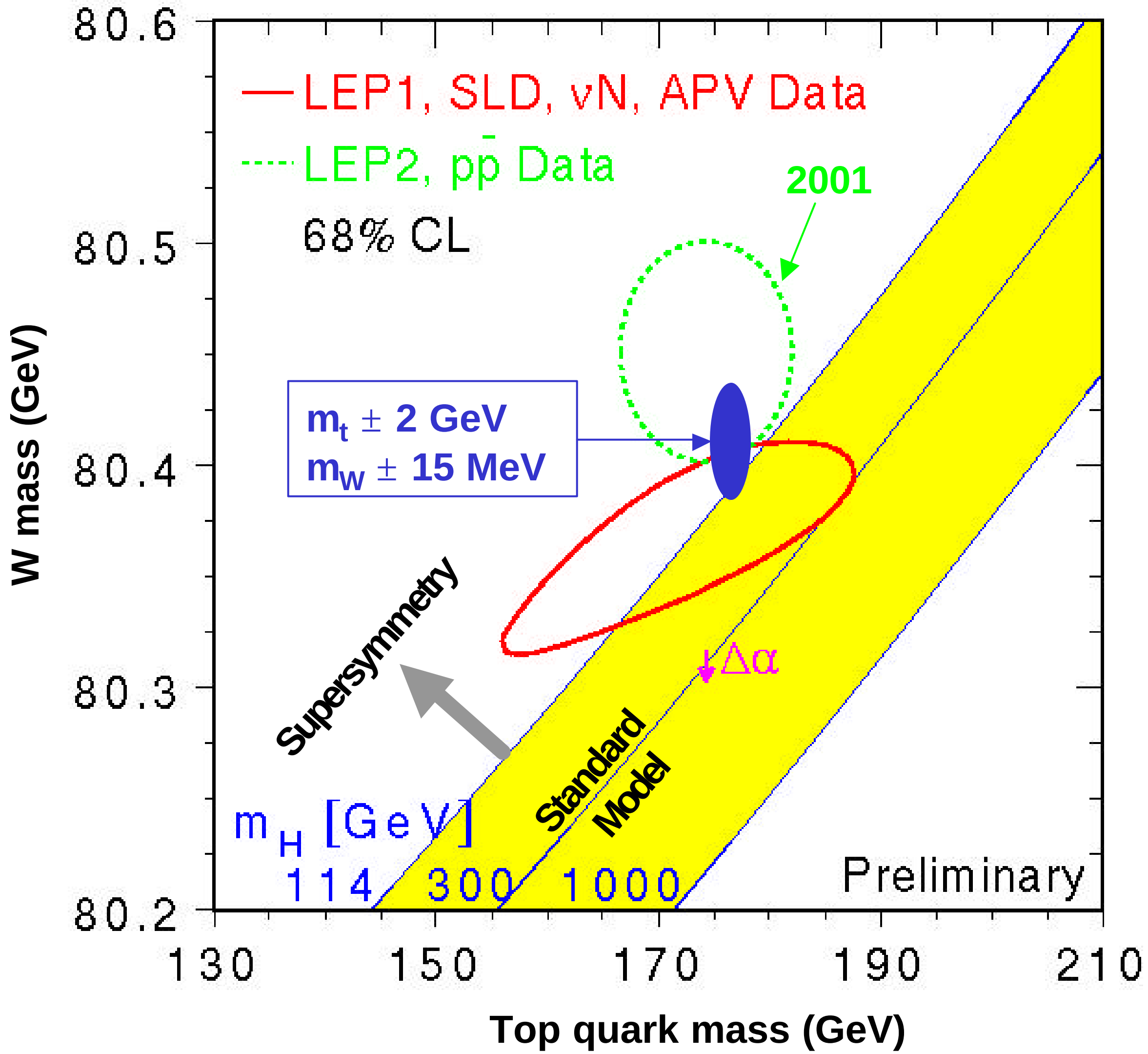
Indirect constraints on new physics from Run 2

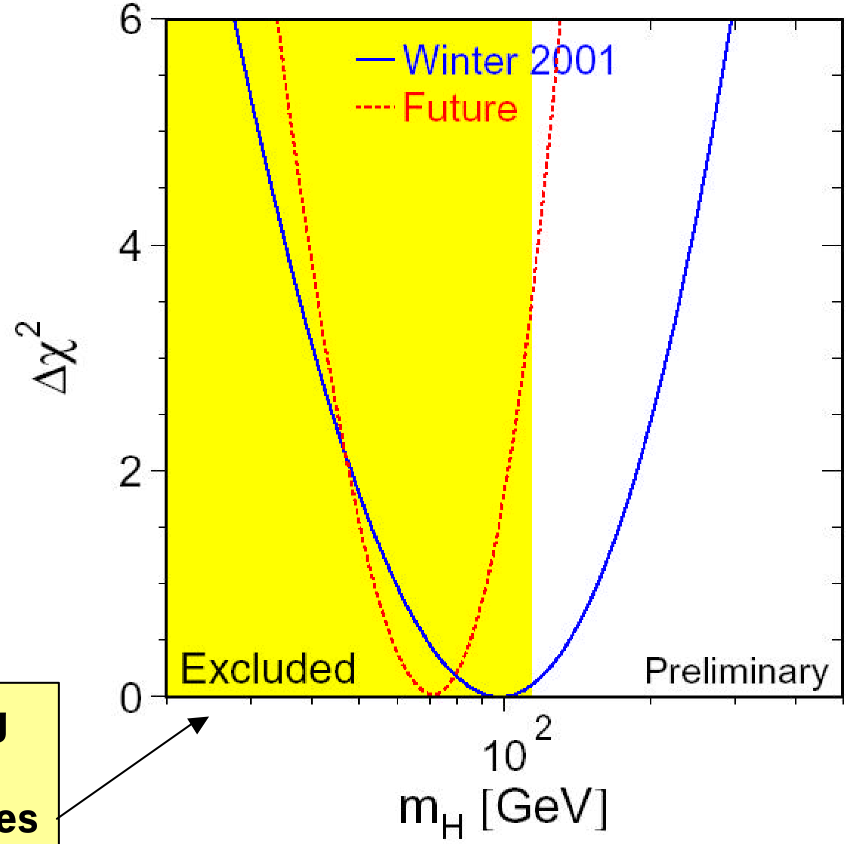


Indirect Constraints on Higgs Mass

- Future Tevatron W and top mass measurements, per experiment

	Δm_W
2 fb^{-1}	±27 MeV
15 fb^{-1}	±15 MeV

	Δm_t
2 fb^{-1}	±2.7 GeV
15 fb^{-1}	±1.3 MeV



Impact on Higgs mass fit using
Dm_W = 20 MeV, Dm_W = 1 GeV,
Da = 10^{-4}, current central values
M. Grünewald et al., hep-ph/0111217

Outlook

SUMMARY

- The Tevatron Run 2 started in March 2001. It is offering one of the most exciting physics programs for the next decade.
- Enormous progress made over the course of the last year in terms of detector commissioning. Entering physics results phase.
- Integrated luminosity delivered so far ~20 pb^{-1}. Expect ~300 pb^{-1} by the end of 2002.
- Preliminary performance results are encouraging and indicate that the upgraded DØ detector will be able to fully exploit the available physics opportunities.
- First physics results already emerging: J/Ψ, W, Z, jet distributions, searches, etc.

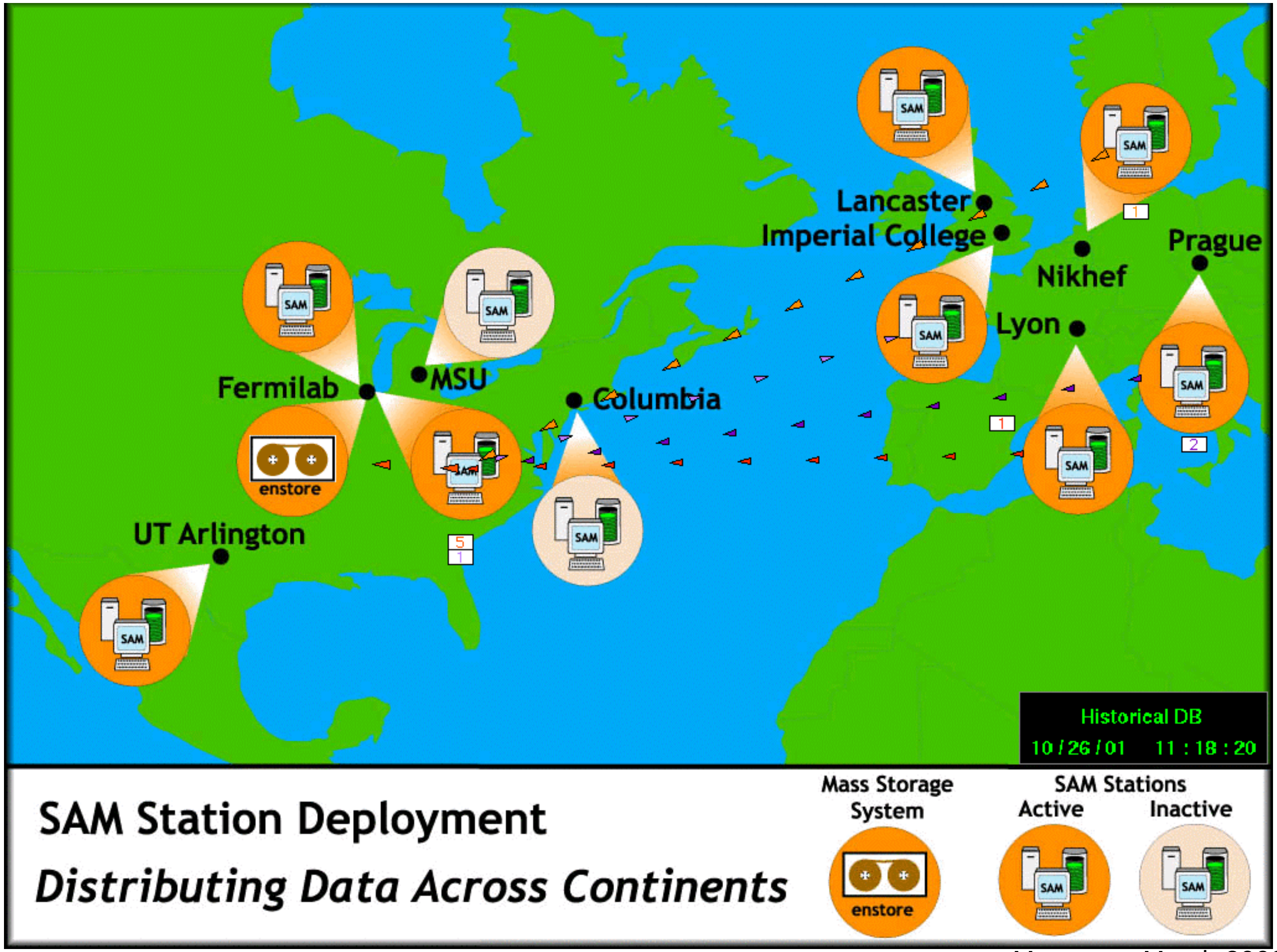
  It will get better:
  - optimization of detector, trigger and DAQ performances,
  - calibration,alignment,
  - improved selection and reconstruction procedures,
  - ...
  - and lots of integrated luminosity

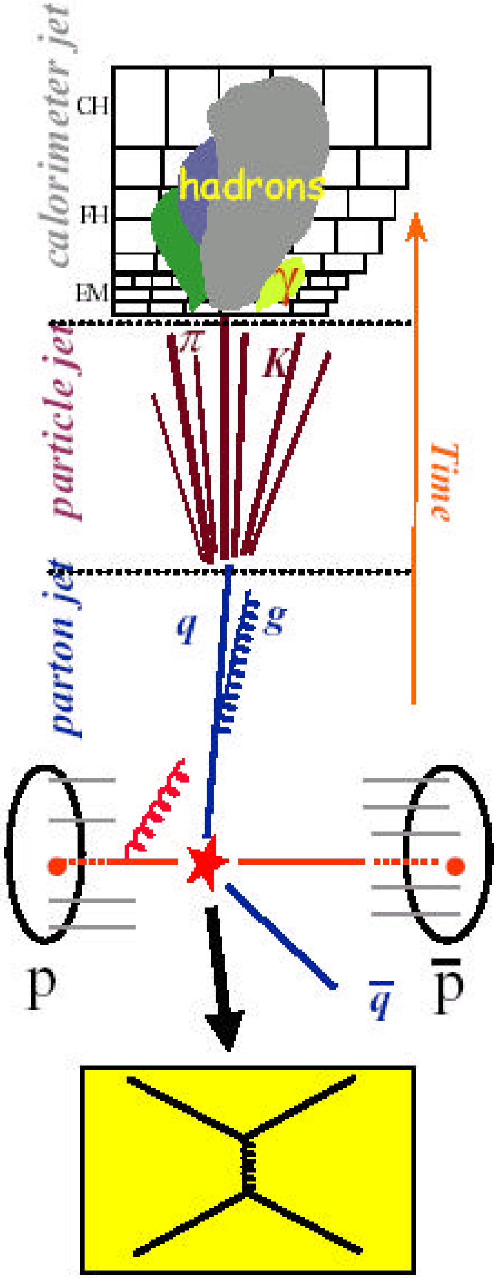
Expect a lot of physics in the coming years

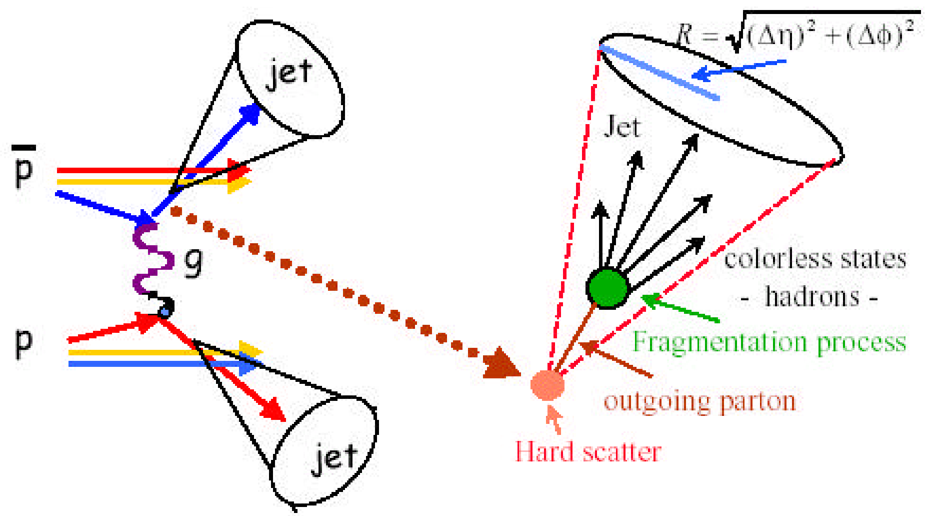
Data Access across the planet

SAM: Sequential Access via Meta-Data

SAM Stations around the world collect and share data for the collaboration




calorimeter jet
CH
FH
EM
hadrons
γ
particle jet
π
K
Time
parton jet
q
g
p
q̄
p̄


p̄
p
g
jet
jet
R = √((Δη)² + (Δφ)²)
Jet
colorless states
- hadrons -
Fragmentation process
outgoing parton
Hard scatter